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THE JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY

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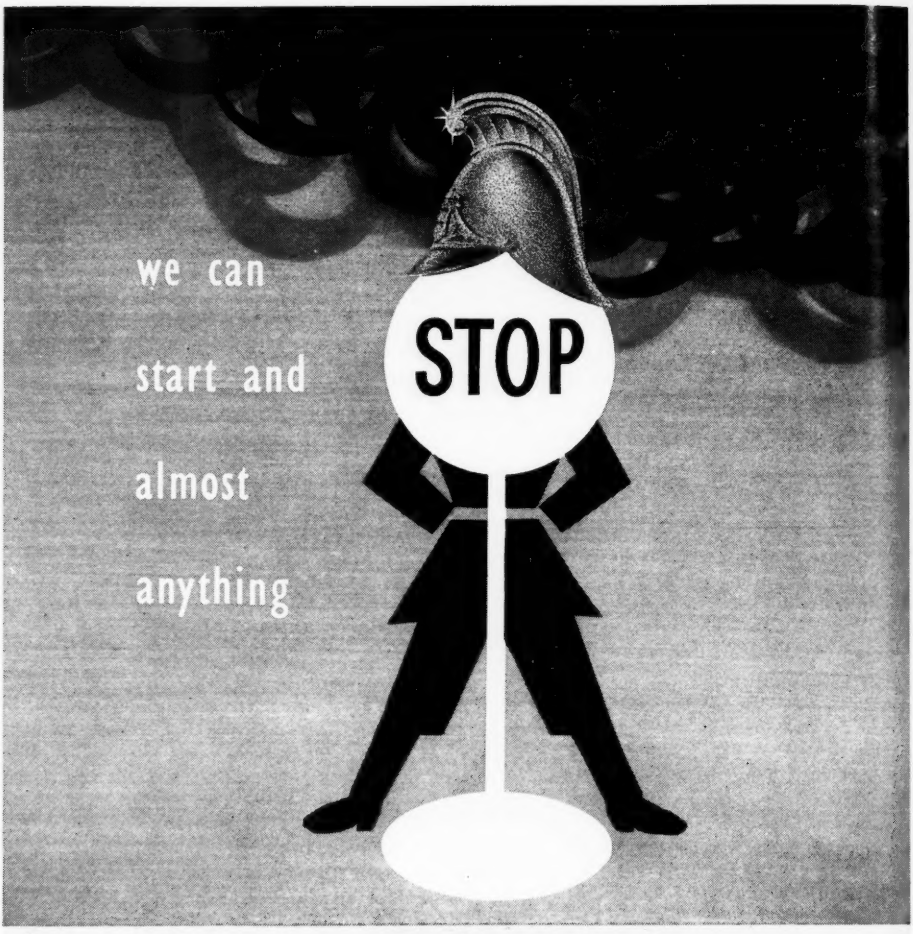

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THE ROYAL AERONAUTICAL SOCIETY

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS

KING GEORGE VI — OUR PATRON

The following message was sent to Her Majesty Queen Elizabeth II by the President on behalf of all members of the Society, expressing their deep regret at the sad loss of their well-loved Patron, his late Majesty King George VI:—

"We, the President and Council of the Royal Aeronautical Society, on behalf of the Council and Members of the Royal Aeronautical Society, wish humbly to offer our condolences to Your Majesty on the great sorrow you and your family have sustained in the death of our beloved Sovereign and Patron the late King, and to present our congratulations to Your Majesty on your Accession to the Throne and respectfully to assure you of our unswerving loyalty and devotion to Your Majesty's person."

A floral tribute was sent on behalf of members at home and overseas.

His Majesty's association with the Society began in February 1920 when he was asked if he would take the Chair at one of the Society's lectures; his Secretary replied that His Royal Highness would be delighted to do so if the date could be arranged out of term time so that his studies at Cambridge University would not be interrupted.

In May 1920, as Duke of York, he first honoured the Society by becoming its Patron, with H.R.H. the Prince of Wales. In that year also he presided at the Eighth Wilbur Wright Memorial Lecture, held at the Central Hall, Westminster, and attended the Council Dinner which preceded it. The lecture that year was given by Commander J. C. Hunsaker of the U.S. Navy and in thanking the lecturer the Duke of York expressed his pleasure that the relationship between the United States and Great Britain was such that Commander Hunsaker had been permitted to supply the Society with much valuable—and hitherto unpublished—data. He also stressed the importance of friendly relations between the two countries.

In 1923 the Society was privileged to have the Duke of York as President of the International Air Congress, which was organised by the

A photograph taken during the International Air Congress, organised by the Society, in 1923. *Left to right*: Lt.-Colonel Mervyn O'Gorman, C.B., D.Sc., F.R.Ae.S.; His Grace The Duke of Sutherland (Under-Secretary of State for Air); Major-General Sir F. H. Sykes, G.B.E., K.C.B., C.M.G., F.R.Ae.S., M.P.; Group Captain H.R.H. The Duke of York, K.G., K.T., R.A.F., Patron of the Royal Aeronautical Society and President of the International Air Congress; and Lt-Colonel W. Lockwood Marsh, O.B.E., A.F.R.Ae.S., Secretary of the Congress and at that time Secretary of the Society. *In front* (*right*): Her Grace the Duchess of York and (*left*) Her Grace the Duchess of Sutherland.

Society. One of the outstanding events of that successful Congress was the Reception to the delegates who were received by the Duke and Duchess of York.

The Duke of York was present at the dance which followed the banquet given to Mr. A. V. Roe, on the 8th June 1928, by the Society, the Royal Aero Club, the S.B.A.C. and the Air League.

After his accession to the throne King George VI once more honoured the Society in 1937 by continuing as its Patron.

More recently His Majesty sent a message to the Society on its 80th Anniversary, in 1946, and in September last he sent a message to the Third Anglo-American Aeronautical Conference. In December 1948 His Majesty honoured the Society by granting it a Charter of Incorporation.

Members will remember always with pride their great privilege in having His Majesty King George VI as their Patron.

NOTICES

March 1952

EASTER HOLIDAYS

The Offices and Library of the Society will be closed from 5 p.m. on Thursday 10th April until 9 a.m. on Tuesday 15th April 1952.

GARDEN PARTY, 15th JUNE 1952

The Society's Annual Garden Party will be held on Sunday 15th June 1952 at White Waltham Aerodrome, near Maidenhead, by kind permission of the Air Ministry and the Fairey Aviation Co Ltd. Full particulars will be announced in the next issue of the JOURNAL.

CONTENTS OF MARCH JOURNAL

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Production Research on Aircraft, L. E. Bunnett.

Some Operating Problems of Future Transport Aircraft, C. Dykes, M.A., M.Sc., A.F.R.Ae.S., A.F.I.A.S.

Reviews. Library. Correspondence.

(An annual sum of £250 is available for premium awards for papers published in the Journal. These premium awards are usually 15 guineas each. Members and non-members of the Society are invited to submit papers on any aspect of aeronautics.)

THE AERONAUTICAL QUARTERLY

It is regretted that the February number of the Aeronautical Quarterly, Part IV, Volume III, is late but it is hoped that it will be available by the end of March.

Part III, November 1951 of the Aeronautical Quarterly is still available. The Contents of Part III, Volume III are:—

Photoelasticity and Aircraft Design	H. T. Jessop and C. Snell
A Note on the Design of Ducted Fans	B. Thwaites
A New Treatment of the Tuned Absorber with Damping ...	D. C. Johnson
A New Approach to Thin Aerofoil Theory	M. J. Lighthill
The Profile Drag of Yawed Wings of Infinite Span ...	A. D. Young and T. B. Booth
Beams on Cross-Girders with Clamped Ends	J. M. Klitchieff
A Direct Aerodynamic Proof of the Biot-Savart Law ...	J. Lockwood Taylor

Copies of Volume III, Parts I and II, are still available from the offices of the Society at 7s. 9d. a copy to members of the Society, post paid, or 10s. 3d. to non-members, post paid.

HONOURS AWARDED TO MEMBERS

DR. H. ROXBEE COX, *Fellow* (Past President) has been awarded the James Clayton Prize of the Institution of Mechanical Engineers, for his contributions to engineering science and practice, particularly in the fields of aeronautics, power generation, and fuel utilisation. Dr. Roxbee Cox is at present Chief Scientist at the Ministry of Fuel and Power.

PROFESSOR J. H. PARKIN, *Fellow*, has been awarded the Honorary Fellowship of the Institute of the Aeronautical Sciences. Only one such award is made in the year to a non-American. Professor Parkin is Director of the Division of Mechanical Engineering of the National Research Council, Ottawa.

REVISED NEW YEAR'S HONOURS LIST

The following members received honours in the New Year Honours. This list replaces that published in the February JOURNAL which was incomplete.

Kt.

Professor L. Bairstow (*Honorary Fellow*)
D. R. Pye (*Fellow*)

K.B.E.

Air Marshal C. W. Weedon (*Associate Fellow*)
T. W. White (*Companion*)

C.B.E.

Air Commodore C. L. Dann (*Associate Fellow*)
Group Captain J. M. Freeman (*Associate*)
H. L. Stevens (*Fellow*)

O.B.E.

Wing Commander G. L. Gandy (*Associate*)

M.B.E.

J. A. Hamilton (*Graduate*)
Squadron Leader F. A. Houghton (*Associate*)

King's Commendation for Valuable Service in the Air

Squadron Leader K. Ritchley (*Associate Fellow*)

NOMINATION OF CANDIDATES FOR COUNCIL

The following is an extract from the By-laws:—

"The Twenty-one ordinary members (of the Council) shall be nominated and elected from among the members of the Society. At the date of their election at least ten shall be Fellows, and one at least shall be in each of the following classes: Associate Fellow, Associate and Graduate.

"Of the ordinary members of the Council, that number necessary to create seven vacancies shall retire annually. The retiring members shall be those with the longest service since their last election but they shall be eligible for re-election.

"Nominations of candidates for election to the Council must be received by the Secretary not later than 10th April in each year and shall include statements in writing by the candidates that they are willing to serve. The nomination forms shall be signed by one proposer and two seconders, all of whom shall be Voters."

Nomination forms may be obtained on application to the Secretary.

ELECTION OF FELLOWS

The attention of members is drawn to the following extract from the By-laws:—

"Elections to Fellowship will be made annually by the Council and will be announced at the Annual General Meeting of the Society. Nominations will be initiated by the members of the Council or by any four Fellows of the Society. It is the duty of the Council to see that the honour is awarded only to persons who have attained a considerable degree of technical eminence in the profession of aeronautics."

Nominations initiated by any four Fellows of the Society should be received by the Secretary on or before 15th April 1952 to give sufficient time for the Council to consider them in time for announcement at the Annual General Meeting in May.

EIGHTH BRITISH COMMONWEALTH AND EMPIRE LECTURE 1952

The Eighth British Commonwealth and Empire Lecture will be given in October 1952 by Mr. R. E. Hardingham, O.B.E., *Fellow*, Secretary and Chief Executive of the Air Registration Board. The exact date and title of the lecture will be announced later.

MEMBERS' NEW APPOINTMENTS

MR. H. T. HILL (*Associate Fellow*) has recently taken up an appointment on the staff of the Ministry of Supply (Air Branch) as a Professional Engineer Grade I in the Directorate of Engine Production. He was formerly with H. M. Colonial Engineering Service.

SQUADRON LEADER W. D. HUNTER (*Graduate*) has recently been appointed Assistant Air Attaché in Stockholm. He was formerly at R.A.F. Technical College, Henlow, Bucks.

FIFTH LOUIS BLERIOT LECTURE, PARIS 1952

The Fifth Louis Bleriot Lecture will be given by H. Knowler, A.M.I.C.E., F.R.Ae.S., Director and Chief Designer, Saunders-Roe Ltd. The Lecture, on "The Future of the Flying Boat," will be given on 12th March 1952 at the Société des Anciens Elèves Ingénieurs Arts and Métiers, 9b Avenue d'Iena, Paris XVI^{e} at 5.0 p.m. A cocktail party will follow to which all British visitors to the lecture are invited. There will also be an official dinner at the Aero Club de France: those wishing to attend the dinner should let the Secretary of the Society at 4 Hamilton Place know immediately so that invitations may be sent to them.

FORTIETH WILBUR WRIGHT MEMORIAL LECTURE 1952

The Fortieth Wilbur Wright Memorial Lecture will be given by Sir Harry M. Garner, K.B.E., C.B., M.A., F.R.Ae.S., Chief Scientist to the Ministry of Supply, on 29th May 1952, on "Prophecy and Achievement in Aeronautics." The Lecture will be held at the Institution of Civil Engineers, Great George Street, S.W.1, at 6 p.m.

PHYSICAL SOCIETY EXHIBITION, 3rd to 8th APRIL

During the Physical Society Exhibition at Imperial College, which will be held from the 3rd to 8th April 1952, a discourse on "Engineering Supersonic Aerodynamics" will be given by Mr. B. N. Wallis, *Fellow*, on Friday 4th April at 6.45 p.m. Tickets and further details may be obtained from The Physical Society, 1 Lowther Gardens, Prince Consort Road, S.W.7.

NORTHERN HEIGHTS MODEL FLYING CLUB, GALA DAY

Members of the Society have been invited to attend the Gala Day of the Northern Heights Model Flying Club which will take place on Sunday 29th June 1952 at Langley Aerodrome, Bucks, when the Queen's Cup Competition will be held.

DIARY

LONDON.

March 11th.

GRADUATES AND STUDENTS SECTION—An Introduction to Supersonics, C. H. E. Warren. 4 Hamilton Place, W.1. 7.30 p.m.

March 25th

GRADUATES AND STUDENTS SECTION—Annual General Meeting; and a talk, illustrated by Films, on Aerodynamic Oscillations of Suspension Bridges, C. Scruton. 4 Hamilton Place, W.1. 7 p.m.

March 27th

SECTION LECTURE—Some Aspects of Civil Jet Aircraft Performance, D. R. Newman. 4 Hamilton Place, W.1. 7 p.m.

PARIS.

March 12th

FIFTH LOUIS BLERIOT LECTURE—The Future of the Flying Boat, H. Knowler. 9b Avenue d'Ilena, Paris XVI[e]. 5.0 p.m.

BRANCHES.

March 12th

Hatfield—Comet Operation, Captain Majendie. de Havilland Aircraft Co. Ltd. 6.15 p.m.
Weybridge—Planning and Aircraft Development, F. Olaf Thornton. Vickers-Armstrongs Ltd. 6 p.m.

March 13th

Isle of Wight—Electronics, P. Jackson. Saunders-Roe Club House, E. Cowes. 6 p.m.
Manchester—The Problems in the Design of Wheels, J. Wright. College of Technology. 7.30 p.m.
Portsmouth—FILMS: Houses in History; Gems of the Rockies; This is Britain; and Turbo Jet Propulsion. Airspeed Ltd. 6 p.m.

March 17th

Halton—Aircraft of World War I. Leading Apprentice D. E. Gibbings. Halton Camp. 6.45 p.m.

March 18th

Belfast—Lecture. College of Technology. 7 p.m.

March 19th

Brough—Airships. Lord Ventry. Electricity Showrooms, Hull. 7.30 p.m.
Coventry—Aircraft Propulsion at Supersonic Speeds. Dr. W. F. Hilton. The Wine Lodge. 7.30 p.m.
Southampton—Development of the Viscount, G. R. Edwards. M.B.E. University College. 7 p.m.

March 20th

Glasgow—Joint Meeting with R.R. Engineering Society. Rolls-Royce, Hillingdon. 7.30 p.m.

March 24th

Halton—Life and Work of Colonel Cody, G. A. Broomfield. Branch Headquarters. 6.45 p.m.

March 26th

Gloucester and Cheltenham—Some Aspects of High Performance Jet Aircraft, Squadron Leader W. A. Waterton, A.F.C. Wheatstone Hall, Gloucester. 7.30 p.m.
Hatfield—Helicopters, Dr. G. S. Hislop. de Havilland Aircraft Co. Ltd. 6.15 p.m.
Yeovil—Technical Brains Trust. The Park School. 7.30 p.m.

March 27th

Isle of Wight—Junior Prize Lectures. Saunders-Roe Club House, E. Cowes. 6 p.m.
Portsmouth—Annual General Meeting. The Airport. 6 p.m.

March 31st

Halton—Lecturette, Junior Member. Branch Headquarters. 6.45 p.m.

April 2nd

Chester—Flight Refuelling, C. H. Latimer-Needham. Grosvenor Hotel. 7.30 p.m.
Luton—FILM and Discussion Evening. The George Hotel.
Weybridge—Why a Delta? S. D. Davies. Vickers-Armstrongs Ltd. 6 p.m.

April 3rd

Glasgow—Annual General Meeting. St. Enoch Hotel. 7.30 p.m.

April 4th

Yeovil—Annual General Meeting. The Park School. 7.30 p.m.

April 5th

Birmingham—Annual Dinner and Concert. White Horse Hotel.

April 7th

Derby—Flying Boats, H. Knowler. Rolls-Royce Welfare Hall. 6.15 p.m.
Halton—Branch Night. Branch Headquarters. 6.45 p.m.

April 9th

Hatfield—Campaigning in Korea: FILM and Commentary, W. Courtenay. de Havilland Aircraft Co. Ltd. 6.15 p.m.
Southampton—Wind-Excited Oscillations of Suspension Bridges, C. Scruton. *A Joint Meeting with the Southern Branches of the Institutions of Mechanical Engineers and Civil Engineers.* University College. 7 p.m.

April 15th

Belfast—Annual General Meeting. College of Technology. 7 p.m.

April 16th

Hatfield—Annual General Meeting. de Havilland Aircraft Co. Ltd. 6.15 p.m.
Weybridge—FILMS. Vickers-Armstrongs Ltd. 6 p.m.

April 17th

Gloucester and Cheltenham—Annual General Meeting. St. Mary's College, Cheltenham. 7.30 p.m.

COMMITTEE MEETINGS HELD IN FEBRUARY

During February eight meetings were held by Committees of the Society. Outside bodies engaged in aircraft engineering and research held seventeen meetings in the offices of the Society.

ASSOCIATE FELLOWSHIP EXAMINATION RESULTS—DECEMBER 1951

The following were successful in the Associate Fellowship Examination held in December 1951:—

PART I

I. F. Burns, Aerodynamics I.

F. J. Butters, Aerodynamics I.

S. G. Corps, Pure Mathematics; Aerodynamics I; Strength of Aircraft Materials and Theory of Structures I.

V. N. Ferriman, Aerodynamics I.

J. F. G. Hart, Aerodynamics I.

M. E. King, Aerodynamics I; Strength of Aircraft Materials and Theory of Structures I.

D. W. Pickston, Applied Mathematics; Theory of Machines; Strength of Aircraft Materials and Theory of Structures I.

D. K. Ray, Applied Mathematics; Theory of Machines; Properties of Matter, Heat, Light and Sound; Strength of Aircraft Materials and Theory of Structures I.

E. C. Turner, Properties of Matter, Heat, Light and Sound.

W. B. D. Wardle, Applied Mathematics; Theory of Machines; Properties of Matter, Heat, Light and Sound; Strength of Aircraft Materials and Theory of Structures I.

J. D. Watkins, Strength of Aircraft Materials and Theory of Structures I.

ABROAD—PART I

Flying Officer W. Raj (India), Applied Mathematics; Aerodynamics I; Theory of Prime Movers.

A. V. Ranga Rao (India), Pure Mathematics (1st Place); Aerodynamics I (1st Place); Theory of Machines (1st Place).

577666 Corporal Thomas, T. W. (M.E.A.F.), Pure Mathematics; Theory of Prime Movers and Fuels; Properties of Matter, Heat, Light and Sound; Strength of Aircraft Materials and Theory of Structures I.

PART II

B. R. A. Burns, Aircraft Design.

R. Boocock, Radio Communications.

M. P. Hanvey, Aircraft Design.

W. A. Page, Air Transport; Aircraft Materials.

G. S. Pool, Aerodynamics II

A. Syme, Engine Design.

F. I. V. Walker, Aircraft Materials.

ACKNOWLEDGMENTS

The Council acknowledge with grateful thanks the return of back numbers of the JOURNAL from The Aeronautical Research Council, the Isle of Wight Branch of the Society, V. G. Jones, Esq., *Associate Fellow*, and Squadron Leader E. F. C. Worthy, *Associate*.

ELECTIONS

The following is a list of new members and transfers of membership of the Society:—

Associate Fellows

John Leighton Benton (*from Graduate*)
George William Bond
Terrence Urban Dunn (*from Associate*)
Arthur Ernest Elmer (*from Graduate*)
Harold Arthur Fenton
James Philip Graham (*from Graduate*)
George Hughes (*from Graduate*)
Maurice Henry Albert Kempster (*from Graduate*)
Arthur Leighton Patterson (*from Associate*)
Thomas Ulric Curzon Shirley
Rodney Herbert Walsh (*from Student*)

Associates

George Albert Victor Bignell
Charles David Hollis (*from Student*)
Walter Miles
John Leslie Miller
Alger Louis Petitjean

Graduates

Malcolm Hesketh Barratt (*from Student*)
William Boulton Clegg
Harold Maurice Dean
Alfred John Wilson Dick
Abdul Mannan Durrani
Albert Henry Eldridge
Dennis James Farmer (*from Student*)
David Wilfred Holland Godfrey (*from Student*)
Barry Mansfield Goldsmith
James Peyton Harding
Douglas Frederick Holwill (*from Student*)
Peter Jefferson
Nigel John McKellar
Gordon Eric Monger (*from Student*)
Ivor Armfield Payne (*from Student*)
Anthony Derek Robinson
Eric William Evan Rogers (*from Student*)
Geoffrey Walter Webber (*from Student*)
Alan Herbert Wickens (*from Student*)

Students

Elie Rahmin Bonan
Daphne Hazel Briggs
John Kirkhope Foden
Stanley Clifford Idle
Kenneth Gerald Lane
David John Lloyd Lewis
James Harvey McClean
William Francis Meichan
Mervyn Brian Packer
Madan Panikkar
Gerald Irwin Secluna
Anthony John Spurgin
Peter Charles George Stalkartt

Companions

Raymond Alfred Arthur Bryant
Robert John Finlay Porter
Henry Norman Thornton

CHANGES OF ADDRESS

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters).

Grade of membership.

New address (in block letters).

Old address.

Changes of address must be received *before the 15th of the month* in order to be effective for the JOURNAL for the following month.

JOURNAL BINDING

Members are reminded that a special leaflet on JOURNAL binding for the 1951 Volume and for 1952 was enclosed with the December JOURNAL. Copies of this leaflet are available on application to the Society.

ANNUAL SUBSCRIPTIONS

Members are reminded that their annual subscriptions became due on 1st January 1952. The rates are:—

	Home	Abroad
	£ s. d.	£ s. d.
Fellows	5 5 0	4 4 0
Associate Fellows	4 4 0	3 3 0
*Associates	3 3 0	3 3 0
Graduates (aged under 26) ...	2 2 0	2 2 0
Graduates (aged 26 and over) ...	2 12 6	2 12 6
Students (aged under 21)	1 1 0	1 1 0
Students (aged 21 and over) ...	1 11 6	1 11 6
Companions	3 3 0	3 3 0
Founder Members	2 2 0	2 2 0

* Any Associate elected before 1st October 1947 may, if he wishes, elect not to receive the JOURNAL, and in this case his subscription will be reduced by £1 1s. 0d. to £2 2s. 0d.

It will avoid delay and confusion if members, when sending remittances for subscriptions, will state their names clearly and give their addresses and grades of membership.

Remittances should be made payable to the Royal Aeronautical Society.

Problems of Transonic Flight

by

A. N. CLIFTON, B.Sc., F.R.Ae.S.

The 834th Lecture to be given before the Royal Aeronautical Society was read under the auspices of the Gloucester and Cheltenham Branch on 22nd November 1951 at St. Mary's College, Cheltenham, by Mr. A. N. Clifton, B.Sc., F.R.Ae.S., on "Problems of Transonic Flight."

The Lecture was attended by Mr. A. E. Bingham, F.R.Ae.S., Chairman, and Mr. G. H. Dowty, President, of the Gloucester and Cheltenham Branch, Major G. P. Bulman, C.B.E., Past-President of the Society, Mr. N. E. Rowe, C.B.E., F.R.Ae.S., Chairman of the Branches Committee of the Society, Dr. A. M. Ballantyne, T.D., A.F.R.Ae.S., Secretary of the Society, and a number of members of the Main Society and members of other Branches.

Mr. A. E. Bingham, Chairman of the Gloucester and Cheltenham Branch, opened the meeting by welcoming the many visitors. The Cheltenham Branch was in its 21st year. Membership had risen from 336 in 1950 to 412, an increase of 76, which was good evidence that the Branch was very much alive. On this special occasion the Main Society had come to Cheltenham and the Branch was both honoured and grateful; the very large attendance at the meeting was a mark of their appreciation. Inviting Major Bulman to preside for the rest of the meeting Mr. Bingham said he was happy to report that Major Halford, the President of the Society, was convalescent and making good progress.

Major G. P. Bulman said that the occasion was indeed important for it marked the 21st birthday of the Cheltenham Branch. The President had asked him not only to express his regret at being unable to be present, but also to offer most sincere congratulations and good wishes for the future prosperity and happiness of the Branch.

The meeting provided every evidence that the Society was wise when it had decided that each year a number of main lectures should be delivered to the Branches; it was a matter for the greatest satisfaction that, in addition to members of the Cheltenham Branch, there were present 46 visitors from Bristol, 31 from Coventry, four from Birmingham and an undisclosed, but very welcome, number from Southampton, Derby and the Isle of Wight.

He would like to take the opportunity to introduce to the meeting Dr. A. M. Ballantyne, the Secretary of the Society. Everyone realised the great work that Captain Pritchard had done in that capacity for many years, and those who had had the opportunity to get to know Dr. Ballantyne during the months in which he had been with the Society had no doubt that he also would achieve a great place and would add to its success in the years to come.

He had much pleasure in introducing the Lecturer, Mr. A. N. Clifton, Assistant Chief Designer, Vickers-Armstrongs (Supermarine) Ltd.

1. INTRODUCTION

The title of this paper may be said to cover almost the whole field of the immediate endeavours of those who are concerned with the design and technical development of military aeroplanes, and especially of fighters. The term transonic is not precise, but may be defined conveniently as applying to those speeds of flight, in the region of the speed of sound, when all the customary aerodynamic design rules cease to operate. Theoretically, therefore, transonic flight consists entirely of problems. Fortunately, in practice, the situation is not quite so disorderly as this would imply. For security reasons this paper cannot include a discussion of flight experience and is restricted to an evaluation of some of the many problems which must be solved in the design of transonic aeroplanes. By this is meant aeroplanes which not only fly, but are capable of being manœuvred under the full control of a human pilot at low, as well as high, altitudes in the transonic region.

These matters are considered under three broad headings; firstly drag and thrust problems, secondly stability and control, and thirdly temperature effects.

NOTATION AND ABBREVIATIONS

A_1	$\partial C_L/\partial \alpha$
A_2	$\partial C_L/\partial \eta$
C_L	lift coefficient (in Fig. 9, of tailplane)
c.p.	centre of pressure
g	acceleration due to gravity
l_θ	wing bending stiffness
m_θ	wing torsional stiffness
M	Mach number
p.s.i.	pounds per square inch
q	dynamic pressure
S	in Fig. 1, denotes wing area, one of the wings having the basic value $S=1.0$
t/c	maximum thickness chord ratio of wing section in line of flight
α	angle of incidence (in Fig. 9, of tailplane)
β	angle of sweepback of $\frac{1}{4}$ c line
η	elevator deflection

2. DRAG AND THRUST

One of the first things to be considered in connection with transonic flight is the large drag increase, and the problem of course is to reduce it. Everyone is familiar with diagrams showing drag coefficient increasing when plotted against Mach number. To the aeroplane designer, the drag, not the drag coefficient, is the important thing, and in order to illustrate this point Fig. 1 shows drag for some wings of different forms, each of which gives the same stalling speed.

Each wing is assumed to have a half-span split flap of width 25 per cent. chord, and allowance has been made for the effect of the different forms upon the aeroplane total weight and hence wing area. Skin friction, assuming leading edge transition, and, in the supersonic case, wave drag are included, but not induced drag. The curves bring out the considerable increase in area which thinness and sweep involve, but the price is worth paying. Size can be reduced by more complicated high-lift devices, but the same is true of all the wings and for any degree of high-lift complication the picture would remain much the same. At a Mach number of 1.3, it would be an achievement to keep the drag increase down to 20 times that of straight wings at $M=0.7$.

Considering next fuselages; for the purpose of drawing the drag curves of the next two figures a body of circular cross section is assumed, having conical fore and aft portions and a cylindrical centre portion; the portions are of equal length with the junctions rounded off. The estimates, in the subsonic case, include skin friction with transition at 10 per cent. of the length and, in the supersonic cases, fully turbulent skin friction as well as wave drag.

Figure 2 is for frontal area fixed and length varied. It will be noted that when length is increased drag is increased subsonically, whereas supersonically it is greatly reduced. Taking advantage of some lengthening, at $M=1.3$ something like 14 times the body drag at $M=0.7$ is indicated. If the frontal area is not the criterion of size, but the volume to house components, then the curves of Fig. 3 with volume constant show that increasing length pays even greater dividends. However at $M=1.3$, 12 or 13 times the subsonic drag is the order of increase. Although these estimates ignore practical details of great importance such as intakes, it seems clear that the long thin fuselage is the thing to aim at. This should encourage our engine designers to produce longer and thinner engines.

Another matter coming under the heading of drag is the importance of surface finish. This has two aspects defined as roughness and waviness. Transonically, roughness is still very important and the difference between a very smooth and a moderately poor paint finish can account theoretically for something like 20 per cent. of the total drag.

Before the advent of the jet engine laminar flow aerofoils were being designed and the required waviness limits were very difficult to achieve. Under transonic conditions, extensive laminar areas appear to be of less importance, but stringent waviness limits must still be met in order to avoid both local shock waves, and also separations causing loss of lift. These separations may induce wing dropping near $M=1.0$, or buffeting or stalling in turns. Light alloy skins with integral stiffeners have advantages in respect to "roughness" by eliminating stringer-skin attachment rivets, and in respect to waviness by making practicable any desired degree of support for the skin. Looked at another way, the integrally stiffened skin can have a simpler supporting structure with members more widely spaced. Fig. 4 shows the relative stiffness under normal loading of two sheets of equal weight. The plain plate is 0.048 in. thick, and the ribbed plate 0.030 in. thick with ribs 0.125 in. deep by 0.12 in.

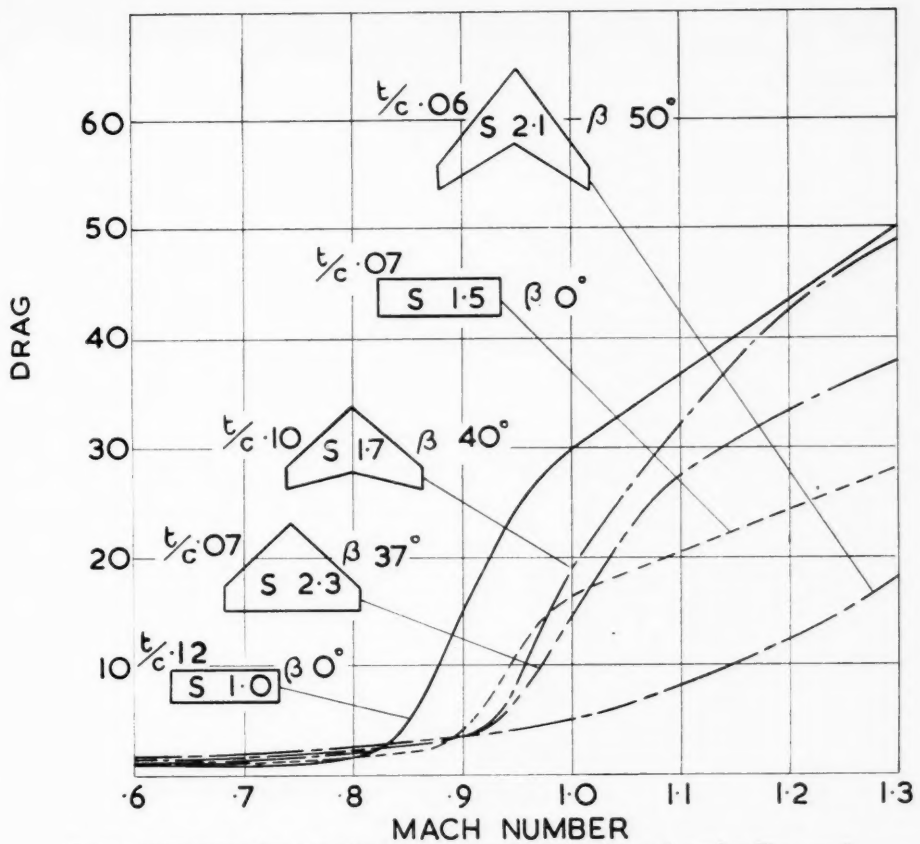

Fig. 1. Wing wave drag plus skin friction at sea level for wings of equal stalling speed.

wide at 2 in. pitch. The ribbed plate has five times the stiffness of the plain one.

In America it is claimed that both cost and weight are saved by integral stiffening, and it is to be hoped that economic methods of manufacturing this material will be developed in this country as quickly as possible. A perfect finish is increasingly worth while.

Complementary to the question of drag is that of thrust. It has been obvious for a long time that large increases of thrust are needed for transonic flight, and no complaints can be made about the rate of development of the jet engine, even though its increasing thirst for fuel is a constant embarrassment. Nevertheless the thrust increases required are tremendous and the engine designer must be urged to press on with all speed. Fig. 4(a) shows the thrust increases needed in order to achieve level flight at $M=1.3$ The basic thrust factor is the factor by which the basic thrust, without reheat, of the present day engine, such as an Avon or Sapphire, must be multiplied. A great problem is the provision of a suitable intake and here knowledge of transonic efficiency is lacking. There is some evidence indicating an unpleasant drop in pressure recovery at the entry around $M=1$ as shown in Fig. 5. Again, where to put the intake remains a burning question. Much more evidence, preferably full scale, is needed on this matter. No more will be said on this subject in view of Dr. Seddon's lecture*.

*Air Intake for Gas Turbines, J. Seddon. Lecture given on 6th December 1951. *To be published.*

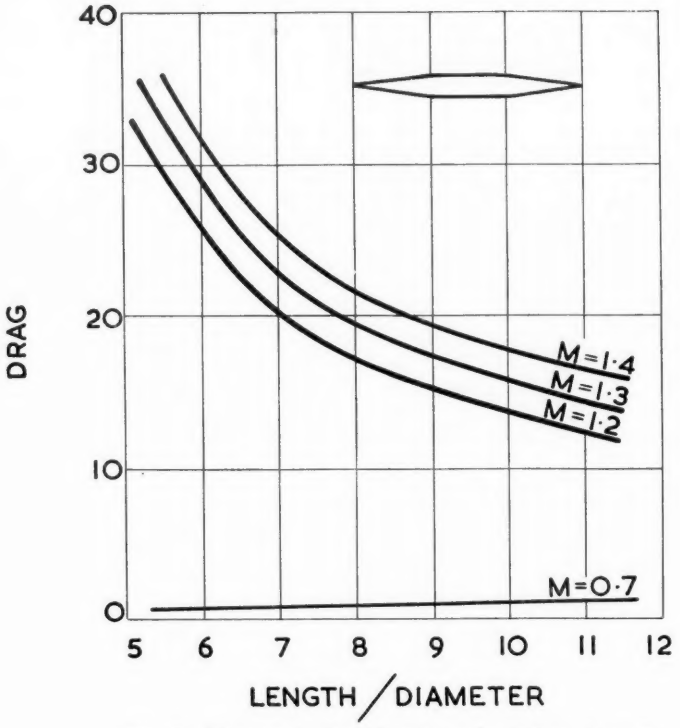

Fig. 2. Wave Drag plus skin friction for bodies of equal frontal area.

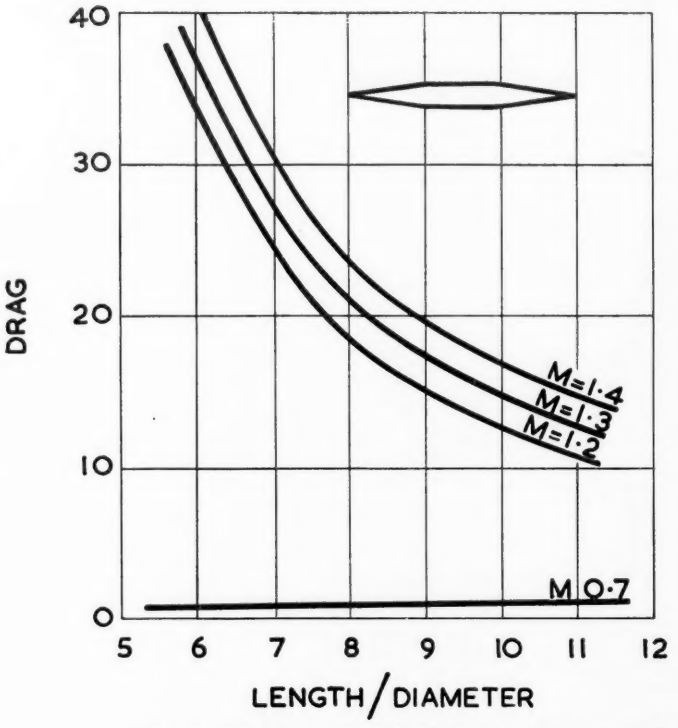

Fig. 3. Wave drag plus skin friction for bodies of equal volume.

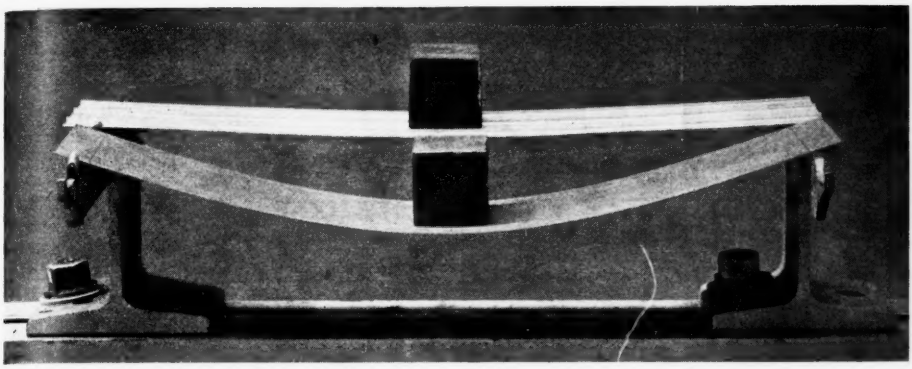

Fig. 4.

3. STABILITY AND CONTROL

Assuming that the desirable state of transonic affairs has been reached when the thrust is sufficient to cope with the considerable drag increases, consideration can now be given to the question of stability, and firstly to static fore-and-aft stability.

Figure 6 shows an estimate of the aerodynamic centre variation with Mach number of two wings, one straight and the other swept back by 45° at the quarter chord. The upper line on each curve indicates the effect of adding the tail. This diagram demonstrates the well-known fact that the changes of trim in the transonic range are less with swept than with straight wings.

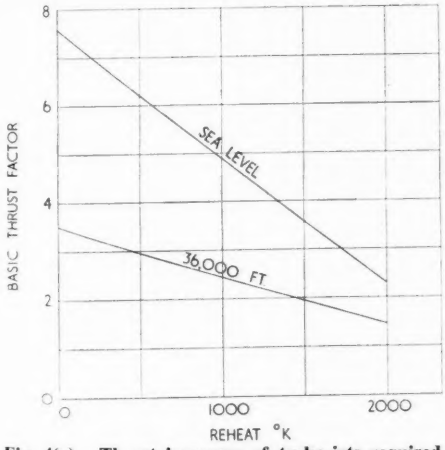

Fig. 4(a). Thrust increases of turbo-jets required for flight at $M = 1.3$.

Considering now the elevator angles necessary with a fixed tail, in order to overcome the out of balance moments and trim the aeroplane, Fig. 7 shows these angles for the swept aeroplane at 40,000 ft. and also at 5,000 ft. Three curves are shown, one assuming a rigid structure and subsonic aerodynamic characteristics, the second with corrections for compressibility and the third with an additional correction for structural deformations. It will be realised that these estimates apply to a given tail setting, in this case 0° relative to datum. If the tail setting is charged by one degree to −1° in order to reduce the elevator angles, a disproportionate improvement results, as shown in Fig. 8. This indicates the importance of a correct choice of tail setting and also has a bearing on the question of the variable incidence tail.

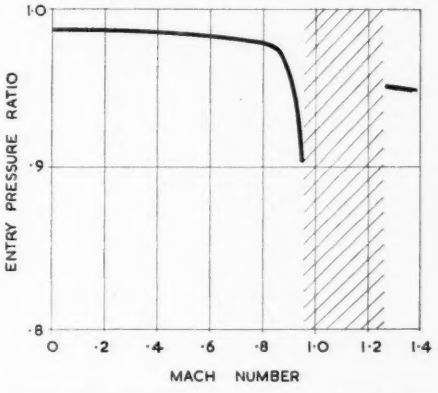

Fig. 5. Pressure recovery at entry typical intakes.

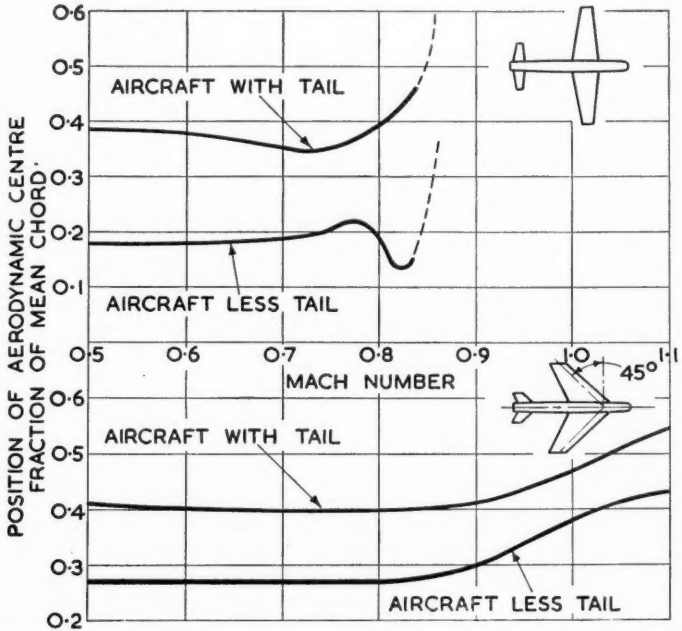

Fig. 6. Variation of aerodynamic centre position with Mach number.

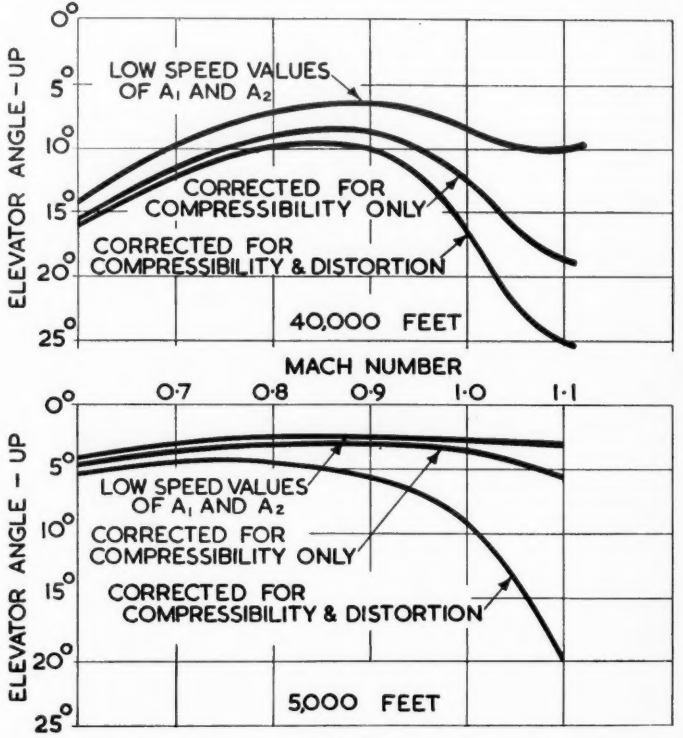

Fig. 7. Estimated elevator angles to trim for an aircraft with surfaces swept at 45°.

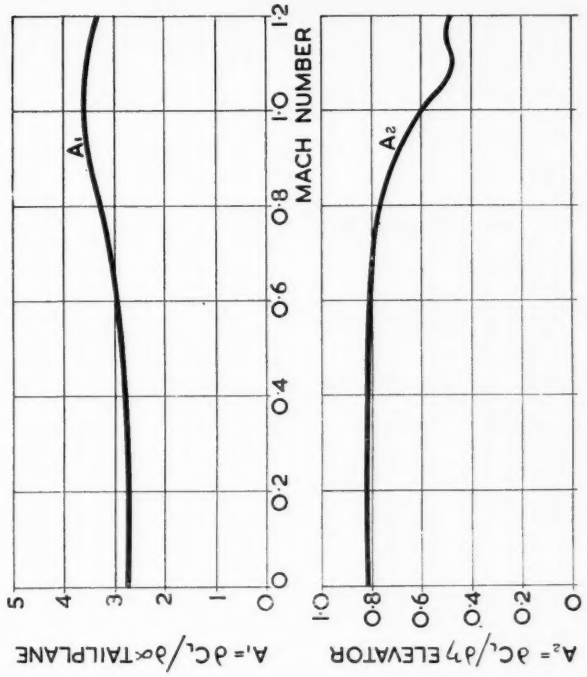

Fig. 9. Variation of A_1 and A_2 with Mach number.

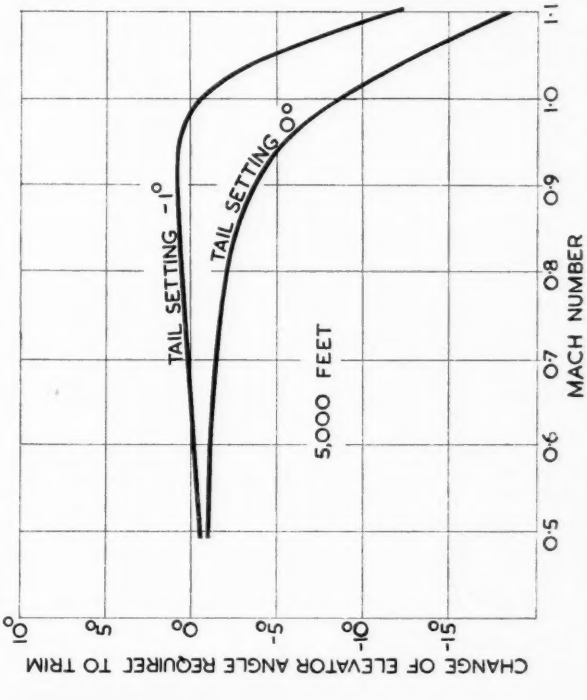

Fig. 8. Effect of tail setting on change of elevator angle due to distortion.

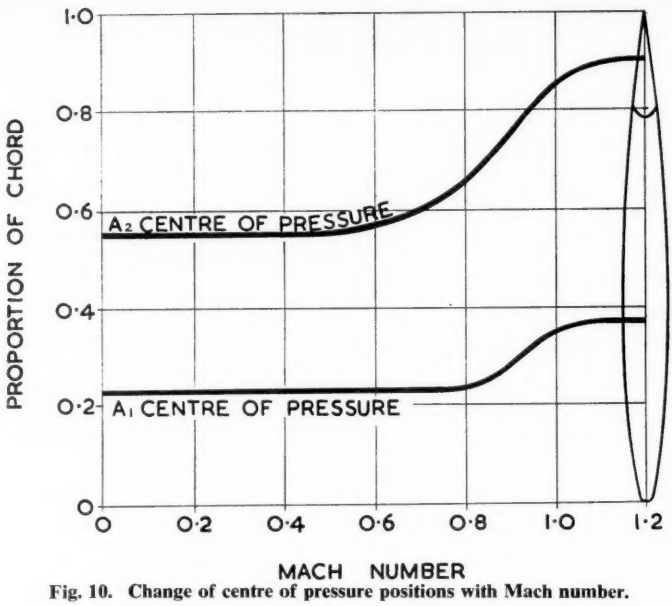

Fig. 10. Change of centre of pressure positions with Mach number.

These curves are calculations and a word or two is necessary about the method used for assessing distortion effects. Fig. 9 shows the variations of A_1 and A_2 which have been used in the evaluation of elevator effectiveness. Whereas the change of lift with incidence on the fixed surface improves with increasing M, the opposite is true of the moving surface. The next curve (Fig. 10) shows the rearward shift of the centre of pressure of tailplane lift A_1 and elevator lift A_2 as M is increased. The effects of these factors upon elevator effectiveness are shown in Fig. 11. The calculations are based on strip theory, assuming that forces on any strip in the line of flight depend only on local conditions and induced effects are ignored. The mode of distortion is chosen at the start, and the magnitude only is allowed to vary. The coefficients are obtained from scanty model data at the wrong Reynolds number. The theory, like all theories, has its limitations, but the curves do show the type of thing which is liable to happen.

The increasing effect of structural distortion may be noticed as M is increased, and also as height is decreased. Important components of this distortion are the bending and torsional deflections of the tailplane, when of swept plan form, and both have the same effect of decreasing elevator effectiveness. In order to appreciate the relative importance of these deflections, lines of constant elevator effectiveness can be plotted for various combinations of torsional stiffness m_θ and bending stiffness l_z, at limiting Mach number (Fig. 12). If the required elevator effectiveness has already been decided only the one line need be plotted. With a knowledge of the costs in weight of stiffening the tailplane flexurally and torsionally, it is a simple step to decide on the most efficient flexural-torsional relationship. At high transonic speeds elevator effectiveness is bound to be low and the type of stressed skin construction in which the material resists both bending and torsion shows up to advantage. Skins with integral stiffeners are again necessary.

When the structural stiffness has been dealt with as far as possible, the elevator is still in all probability rather ineffective, and the forces large for the pilot to hold, bearing in mind the rather rapid changes of trim which can occur under transonic conditions. The question arises as to how far past practice may be relied on in the form of trimmer tabs, plus spring tabs and possibly power boost.

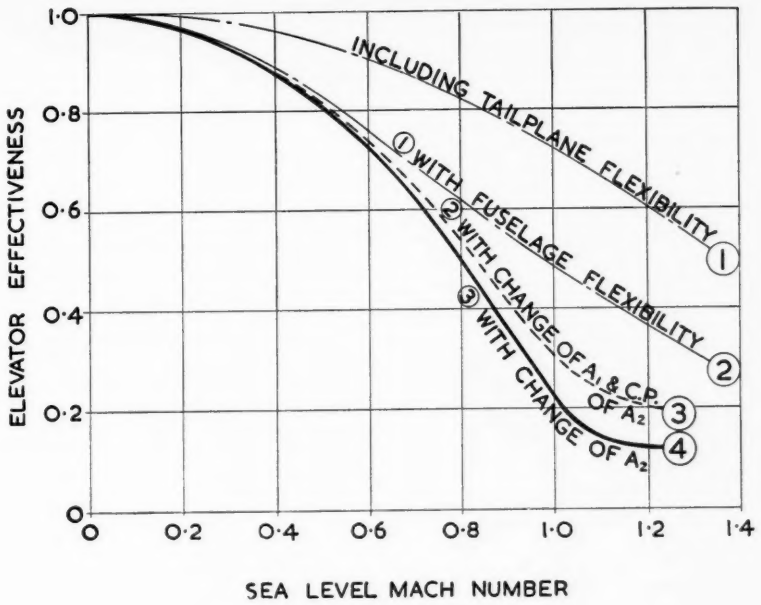

Fig. 11. Loss of elevator effectiveness.

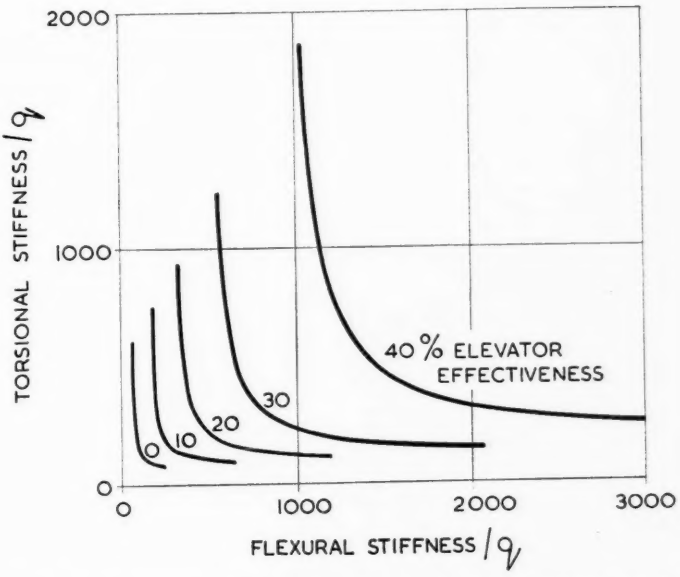

Fig. 12. Variation of elevator effectiveness with tailplane stiffness at limiting Mach number.

American practice, and perhaps the trend here, is to adjust the tailplane incidence for trim. In some cases variation of tailplane incidence is used as a control.

This raises the subject of fore-and-aft control, as distinct from trim. Even on a rigid aeroplane the stick force per g, the conventional measure of manœuvrability, would increase considerably at high Mach number due to the shift of the wing aerodynamic centre alone. When the loss of elevator effectiveness from both aerodynamic and structural causes is added, the result is a very large increase in stick force per g which certainly requires spring tab or power aids in order to give satisfactory forces. This situation is improved if it is decided to use the tail for trimming because then an elevator of smaller chord can be used. (It was found in one case that the saving in weight on the smaller elevator with its attendant mass balance was sufficient to cover the weight cost of changing from fixed to moving tail.) Even though the elevator chord is reduced by this means, a spring tab or power booster will probably still be needed. A factor which must be considered is what happens if there is a power failure, either of the tail trimming or of the elevator boost. Taking it all round, the best scheme for transonic flying seems to be a small-chord elevator, power-boosted, with tail-incidence change regulated by elevator angle. This gives automatic trimming and a reasonable chance of manual reversion if the power boost fails. Again it should be possible to fly the aeroplane in emergency if the trimming arrangements, *i.e.* the tail-incidence change, should fail. By using say, hydraulic boosting and electrically-operated incidence change, the possibility of a simultaneous failure of both is eliminated, and duplication is achieved for little or no weight cost. The automatic trimming is a useful feature which maintains small elevator angles in relation to the tail and minimises elevator ineffectiveness, without calling for any trim action from the pilot. Compared with the practice of ten or fifteen years ago there is considerable complication and extra weight. Unfortunately, this is a recurring theme in the design of transonic aircraft.

Before leaving fore-and-aft characteristics, mention may be made of the tendency of swept wings to become longitudinally unstable at large incidence, due to loss of lift on the wing tips. This feature occurs at a progressively lower lift coefficient as Mach number is increased. The result, in flight, is that in tight turns the stick force per g tends to zero or even becomes negative as M is increased, particularly at altitude. This may prevent full utilisation of lift for manœuvring purposes, depending upon how far control can be maintained in the unstable condition. Again, depending upon controllability in the unstable condition, there is a possible danger of breaking the aeroplane by putting on high g unintentionally. This danger, where it exists, is confined to certain conditions of flight, as shown in Fig. 13. No pilot will put on $11g$ or so without noticing it, but it is worth remarking that the danger area extends to low altitude and high M, when the elevator could be inefficient and control in an unstable condition difficult.

Considering lateral control, there is a familiar problem, aileron reversal, which is similar in nature to the problem of retaining elevator effectiveness. On straight wings torsional stiffness is needed to combat aileron reversal; sweep has added a need for flexural stiffness. As on the tailplane, the advantage of material which resists both bending and torsion is again apparent. On an aeroplane of swept plan form the aileron reversal case may well fix the weight of the torsion material and also any bending material which is swept back, as opposed to the bending material straight across the centre section. An analysis of a typical swept wing may be of interest. The requirement is for 1.44 times the stiffness required to give aileron reversal at maximum diving speed. In Fig. 14 the aileron reversal curve is shown plotted on a framework of

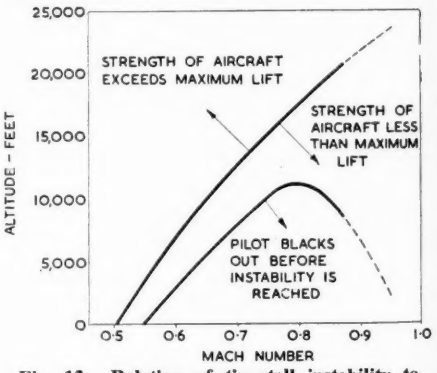

Fig. 13. Relation of tip stall instability to strength of structure.

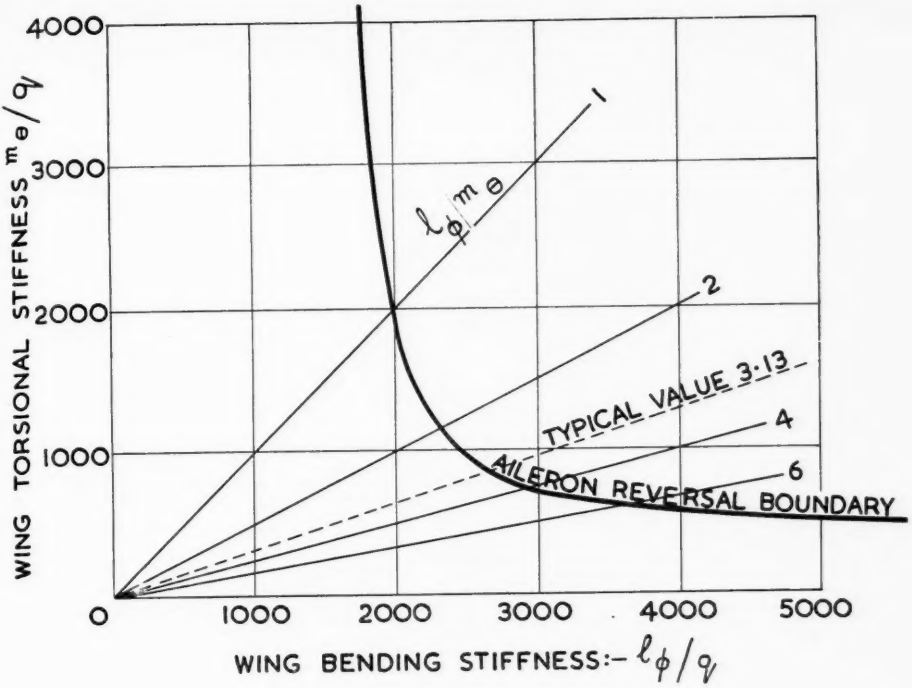

Fig. 14. Wing aileron reversal curve.

bending and torsional stiffnesses. Fig. 15 shows the weight of spar booms and wing torsion skin for different ratios of bending to torsional rigidity, required to supply 1.44 times reversal stiffness. The ratio is not very critical but it does call for low flange stresses. This spells extra structure weight, which cannot be avoided at present.

In designing to provide satisfactory characteristics, particularly for control and stability, on transonic aeroplanes, there is a lack of full-scale data and information with which to check calculations. It is this absence of factural data which is forcing designers to increased weight and to the greater complexity of power controls and variable-incidence surfaces. Such devices should not be accepted as permanent. They may be only a symptom of our present ignorance.

4. TEMPERATURE EFFECTS

Some temperature effects which were not previously important become apparent at transonic speeds. Fig. 16 shows the well-known temperature rise due to velocity ram plotted against M at sea level in the tropics. The probable aeroplane skin temperature rise is assumed to be 85 per cent. of the theoretical and is also shown. Skin temperatures, due to this effect, of the order of 100°C. will arise around $M=1$ low down in the tropics. Two problems arise; firstly structural, especially in relation to plastic components, and secondly mechanical, in providing temperature control apparatus for the pilot and any other temperature-sensitive items.

Considering canopies, which almost universally incorporate acrylic resin transparencies Fig. 17 illustrates what happens to the bending strength of this material as temperature is increased. Fig. 18 shows the tensile strength of unplasticised acrylic resin plotted against temperature of outside surface and equivalent Mach number derived from the previous curve. For some time the relationship given by the lower curve had been assumed; this represents the state of affairs

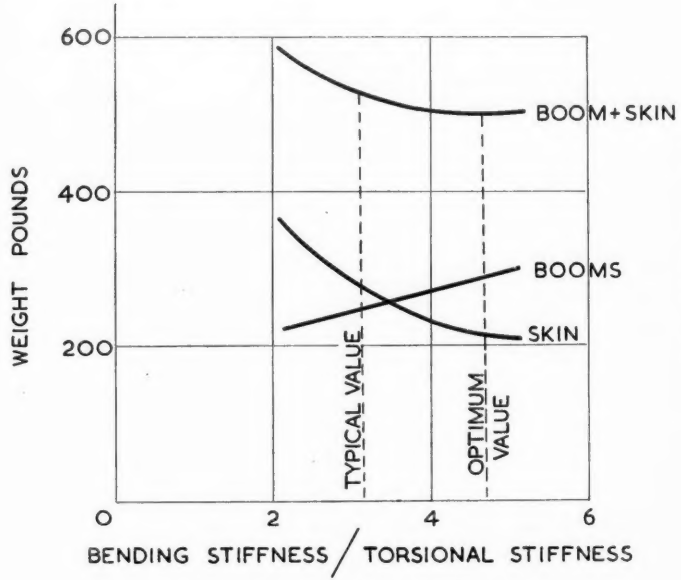

Fig. 15. Weight of boom skin combinations for constant aileron reversal speed.

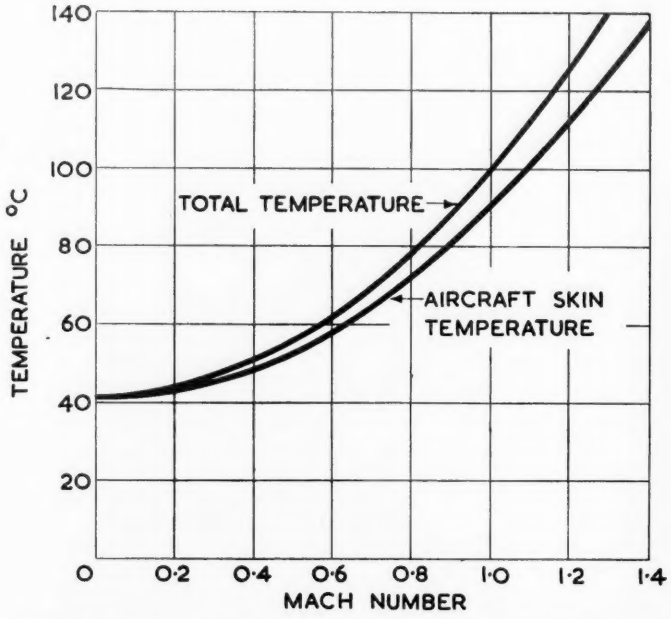

Fig. 16. Temperature due to velocity ram at sea level in tropical summer.

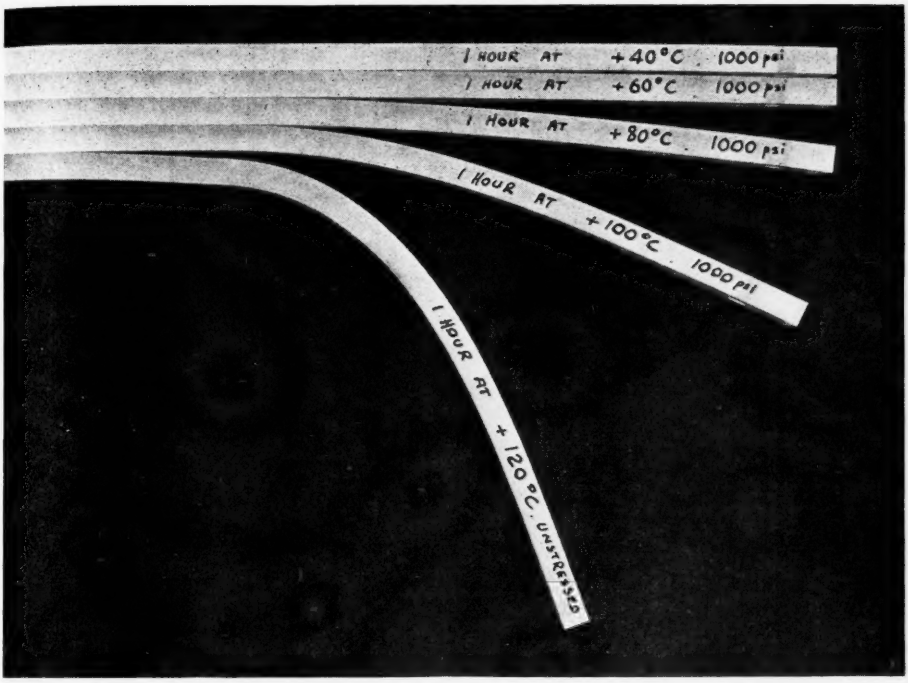

Fig. 17. Strength of unplasticised acrylic resin after one hour at elevated temperatures.

when the temperature is uniform through the whole thickness of the material. However, it is clear that the inner surface with a single-skin canopy will be at some lower temperature because a cockpit temperature of much more than 30°C cannot be allowed. The question of the strength of acrylic resin with a temperature gradient across the thickness then arises. From tests done so far, it would appear that something like the strength equivalent to the mean temperature applies. On this basis, and if, for example, an inner surface temperature of 30°C. is taken, the relationship given by the upper curve of Fig. 18 results. It will be apparent that even with this relief the present material can hardly be used for single-skin canopies beyond $M = 1.4$ at tropical temperatures and low altitudes. Failing anything else, glass windows will have to be fitted for higher speeds. Unfortunately both acrylic resin and glass are very unsatisfactory engineering materials and something better is badly needed.

Turning now to the aeroplane structure, light alloys have rather better properties than acrylic resin (*see* Fig. 19). Even so, at 150°C. there is a substantial loss in strength of bar material and an appreciable loss for sheet. The modern jet engine, of enormous power and housed inside the structure, gives off large quantities of heat. In attaining the greatly increased powers needed for transonic flying, there is no doubt that engine temperatures will increase. In the interests of minimum frontal area, clearances between engine and structure are small. (A one-inch clearance round an Avon engine adds about one square foot or 10 per cent. to its frontal area.) Therefore clearances are kept to a minimum and air is circulated internally for cooling. When the air enters at about 100°C. large quantities will be needed to keep the structure down to, say, 150°C., and great ingenuity will be needed to avoid a good deal of added drag from this cause. On the upper diagram of Fig. 20 an estimate of the air flow required

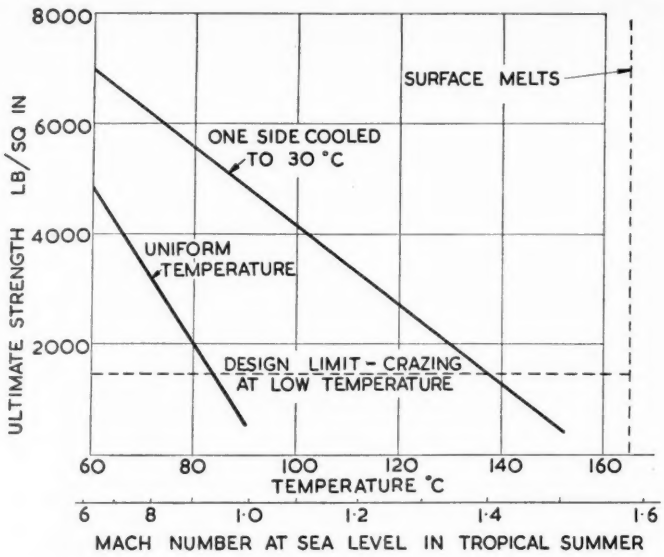

Fig. 18. Strength of unplasticised acrylic resin at elevated temperatures.

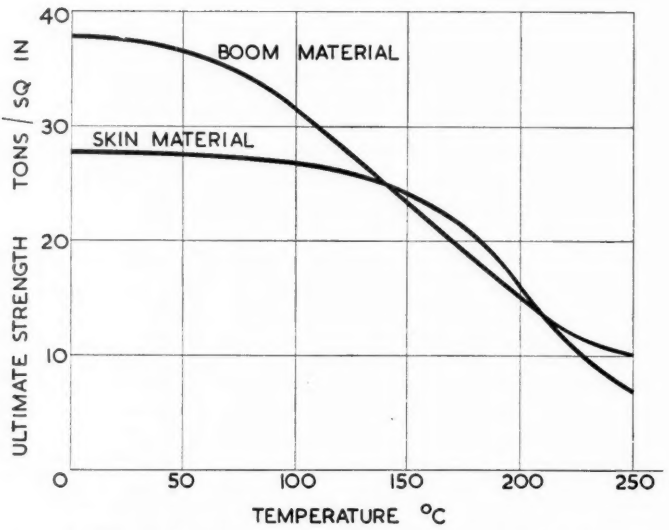

Fig. 19. Strength of light alloy at elevated temperatures after 100 hours.

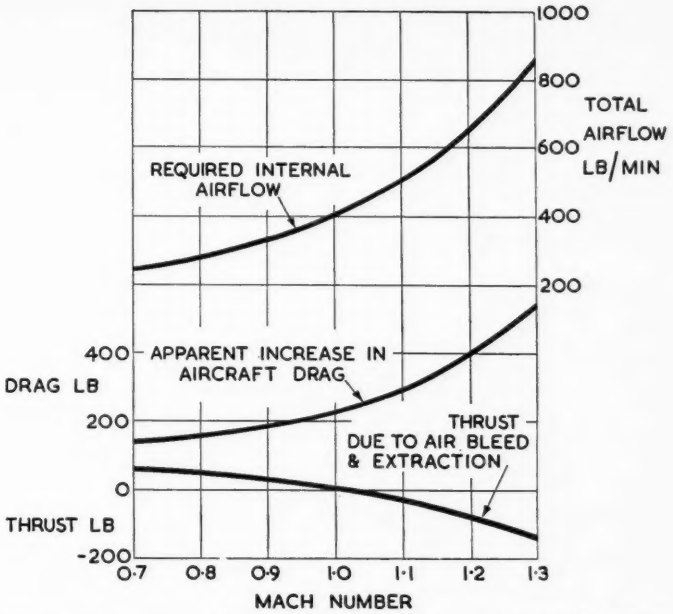

Fig. 20. Secondary cooling at sea level in tropical summer for typical fighter.

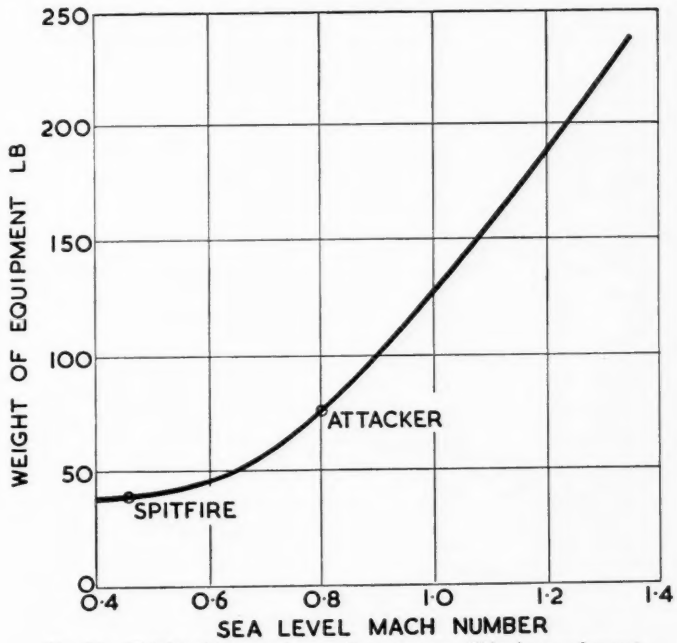

Fig. 21. Weight of temperature and pressure conditioning equipment for typical fighter.

on a typical fighter aeroplane for secondary cooling and ventilation is given and on the lower diagram the estimated increase in drag and loss of engine thrust from this cause.

As soon as the temperature limitation for any item is below, or even near, the stagnation air temperature, apparatus must be installed to cool the air supply. Under certain conditions this is already necessary for the pilot, gun ammunition, and some radar components. As under other conditions heating and pressurising are required, complete air conditioning apparatus must be installed to maintain temperatures and pressures which are always within the desired limits. This involves a piece of engineering which must be made extremely reliable in operation. There is a weight penalty and Fig. 21 shows the trend of this.

These penalties of weight and drag are substantial and they have a considerable upward tendency.

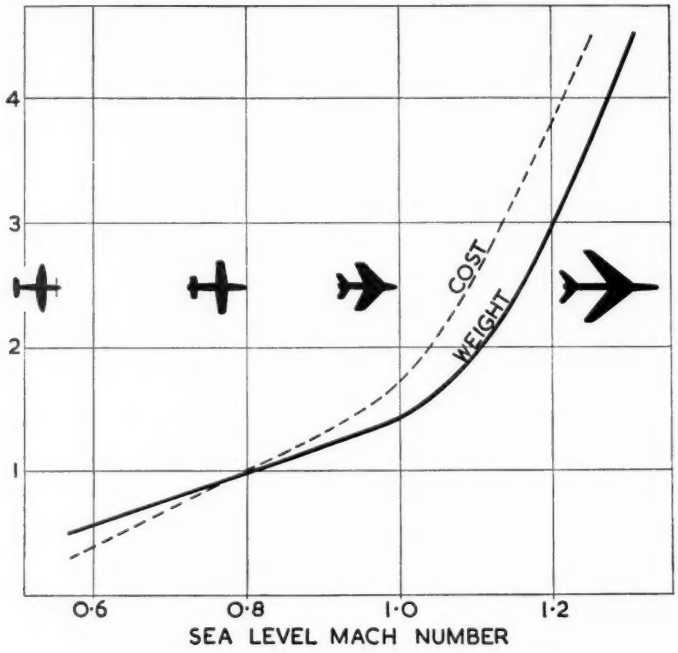

Fig. 22. Weight and cost trends of transonic aeroplanes.

5. CONCLUSIONS

This paper has included some of the more obvious problems which face designers in attempting to design aeroplanes to fly transonically, not merely as a specially organised feat, but as a day-to-day routine job. With present knowledge these problems can be solved only by adding more weight and complication, and increasing the size and cost of aeroplanes. Designers of naval aircraft may find themselves unable to adopt size and weight increases due to the limitations imposed by aircraft carriers, and the disparity between the performance of the land-based and ship-based aeroplanes will then become larger. To counter this, still larger lifts, and wider decks and hangars will be needed.

It is not difficult to make an estimate of the probable rate of size and cost increases which may be expected in the transonic years immediately ahead, based upon the factors

mentioned; Fig. 22 shows the result predicted by the author. No claim to great accuracy is made in these estimates, which are based on a constant military load and endurance, and an improving aerodynamic form. Where cost is concerned an increase in cost per pound to cover increased complication has been assumed. It seems clear that, on the way to the supersonic plateau, not only an aerodynamic cliff but also an economic cliff must be scaled. This economic cliff is reflected in the size, complication and cost of the product (or alternatively in the man-hours needed for its production). It is also reflected in the size of design staffs and prototype manufacturing organisations. As a result of research the steepness of the drag rise is being alleviated, and by the same means the steepness of the cost rise will also be alleviated. At present, however, there is a lack of full-scale data with which to check calculations. This is because there are so few suitable aeroplanes available for taking measurements in flight. With the realisation that the experience of subsonic conditions gained over the past 40 years is often useless and even misleading, it is of the utmost importance that as new aeroplanes come into production some should immediately be allocated and used for research and development purposes. Even if this is done, it will not, by a given date, reduce the cost of aircraft; but what is much more important, a better product will be obtained. The day will thus be brought closer when aeroplanes operate as a normal thing in the transonic region, and when problems of transonic flight hardly exist.

Acknowledgments

The author is indebted to many people for co-operation and assistance in connection with this paper. Firstly, to the Supermarine Works of Vickers-Armstrongs Ltd. for permission to give it, and secondly to his colleagues of the Supermarine Design Staff who have supplied many suggestions and helpful criticisms, and have gone to much trouble in preparing the curves and slides. Without their assistance this paper would not have been possible. The opinions expressed are the author's personal responsibility.

DISCUSSION

Handel Davies (Royal Aircraft Establishment, *Fellow*): The diagrams in Fig. 7 were very instructive, emphasising the fact that compressibility effects did not constitute the only problem, but that aeroelastic distortion effects could also be extremely important. He thought that Mr. Clifton would agree, however, that variations of the kind shown in Fig. 7 could often be made acceptable by using power controls, variable incidence tailplanes, and so on. It was much more difficult to cope with the more rapid variations in trim and stability which were liable to occur due to compressibility effects, in the transonic speed range, even with the 45° swept-back wings.

The lecturer had also mentioned the aeroelastic problems which made it difficult in these days to achieve anything like adequate rolling control on aircraft travelling at very high speeds at low altitudes. This became particularly difficult with aircraft having swept-back wings. They had reached a stage at which the attainment of anything like the rate of roll needed for a good ground support aircraft was becoming practically impossible with the very thin wings which were inevitable if high speed were to be achieved, unless the aspect ratio were to be made very small. What did Mr. Clifton think of the possible use of spoiler control under those conditions, which would relieve to some extent the aeroelastic distortion problems involved?

The proposal that good longitudinal control might be provided by a variable incidence of the tailplane actuated by elevator movement was interesting and he felt certain that the thought behind it was a good one basically, but he could not see how it could be made a really practicable proposition because of the difficulty of achieving tailplane movement characteristics which would be satisfactory throughout the speed range. Taking the extreme case of the elevator moving very closely with the tailplane, it meant that by extra complication they had precisely the same control as that of the all-

moving tailplane with elevators, whereas if the tailplane lagged behind the elevator and moved at a slower rate there would be difficulties arising from overshoot. It would be very difficult to achieve a rate of operation of the tailplane which would be right at the low speed end and at the high speed end as well. He agreed that there was great attraction in using a small-chord elevator combined with the variable-incidence tailplane, but his own view was that the tailplane should be moved by independent means. Heaven forbid that they should have any more buttons on the stick, but that seemed to be a way out of the difficulties. It should be remembered that longitudinal control had to provide two things: (*i*) a means of controlling the aircraft in normal steady flight, requiring very small control movements to maintain steady flight and (*ii*) a means of coping with the large trim changes throughout the speed range. Therefore, it seemed that there should be a variable-incidence tailplane for the large trim changes and a small-chord elevator for normal flying at steady speeds.

Looking to the future, he felt that strong efforts should be made to arrest the trend towards excessive complication. There was no question that for the time being they were being forced to power controls, automatic stabilisation, and so on; but if they did not try to arrest the continued trend towards further complication they would find they had a very small number of magnificent aeroplanes which would spend a large part of their time on the ground in an unserviceable condition. The problems of effecting simplification by reverting, for example, to manually-operated controls were very great, but efforts in this direction were well justified at the present time.

B. P. Laight (Bristol Aeroplane Co. Ltd., *Associate Fellow*): In Section 2 of the paper Mr. Clifton had presented data on the drag of various wing arrangements but, perhaps intentionally, he had refrained from saying what his choice would be.

The problem of drag and thrust was the one most likely in the initial stages to dictate the shape of the aeroplane, and it also bore on the important question as to whether the performance they aimed at would be achieved.

In Fig. 1, dealing with the shapes of various wings, Mr. Clifton had rightly concentrated on what was perhaps the main problem in connection with the supersonic aircraft, *i.e.* that it was necessary to provide sufficient wing to enable the aircraft to take off and land, but that meant usually that the aircraft was carrying too much wing in the supersonic case. Wing drag was only one item in the total drag of a supersonic aeroplane and the drag breakdown for the complete aeroplane should be considered for assessing the importance of the various drag items. When this was done the results in some cases would be at variance with what was generally expected for supersonic aircraft.

Skin friction was still a big item in supersonic drag; it might be of the order of 20 per cent. Wing wave drag might be of the same order, or less with extreme sweepback, and this would suggest that the wing should not be chosen on the basis of Fig. 1 alone.

Canopy drag might again be about 20 per cent. of the total and on this count a prone pilot position would be very useful. Induced drag, sometimes excluded in supersonic aircraft analyses, could be of the same order at high altitude.

To overcome drag there was a tendency to resort to reheat, but a point to be borne in mind in that connection was that it was extremely expensive in fuel, and as soon as someone produced a satisfactory supersonic aeroplane there would be requests for increased fuel capacity. It was well known that an increase of thrust of between 50 and 75 per cent. meant an increase in fuel consumption of the order of two, so that the total fuel consumption was about three times as much as before that increase was effected.

Mr. Clifton had mentioned the static effects of aeroelasticity; had he come up against the problem of dynamic effects, *i.e.* flutter? It was found in one particular case that wing flutter would be covered by the amount of structure put in for strength requirements, provided that the factor was high, but if the supersonic aeroplane were built at a moderate factor the flutter problem might design the structure.

J. F. Cuss (Gloster Aircraft Co. Ltd., *Associate Fellow*): Had the American machines which had already reached the transonic range of which Mr. Clifton had spoken, exhibited the sort of troubles indicated in his illustrations?

The loss of elevator efficiency due largely to structural deformation was shown in Fig. 7; what sort of layout of wing, fuselage, tailplane and elevator combination had Mr. Clifton in mind for that loss of structural

strength or stiffness? It seemed to him that some machines which were now in contemplation would have their tailplanes almost coincident in plan with the trailing edge of the wings, and perhaps the structural deformation should not be so large as Mr. Clifton had indicated, since the length of fuselage was negligible.

The integrally stiffened skin sounded attractive, on the surface. He had an idea that it had been tried in service, but would welcome Mr. Clifton's comments.

He gathered that it was intended to use the skin with the stiffeners running spanwise and not chordwise. If they ran spanwise and an attempt was made to form them to an aerofoil section it would seem to indicate that they would have a series of flats along the chord, with the stiffeners coming in between which would seem to be bad aerodynamically. He did not know if that problem had cropped up.

The integrally stiffened skin being very closely allied to a thick skin in respect of general stiffness, he pointed out that it had been proved, or demonstrated theoretically, that in skins within a certain range of thicknesses there was deformation and buckling, and in a thick skin there was permanent buckling after removal of the load; so that unless one went to a prohibitively thick skin and so avoided buckling or to a thin skin which would buckle under high loads, but would not take permanent set in buckling, one was faced with a situation in which the skin surface would not be free from wrinkles after sustaining high loading in flight. It seemed to him that the integrally stiffened skin partook very much of the nature of the thick skin, and hence would suffer from permanent set troubles. What were Mr. Clifton's views on the matter?

Dr. W. F. Hilton (Sir W. G. Armstrong Whitworth Aircraft Ltd., *Associate Fellow*): He expressed doubt that the wave drag of an ordinary rectangular wing in Fig. 1 should increase with Mach number instead of reducing to a minimum at a supersonic Mach number of 1.41. This minimum was not masked by taking into account the frictional drag coefficient. The drag force should decrease from $M = 1.2$ when the shock wave first attached to the leading edge, up to $M = 1.4$.

Little mention had been made of the delta wing; would Mr. Clifton agree that while the straight-out wing and the swept-back wing both had their several advantages, the delta wing was free from vices, although it was not particularly good in any part of the range? He believed that in particular, it was free from the kind of vices exhibited at transonic speeds by the straight-out wing.

Professor S. C. Redshaw: The lecturer had spoken about the external cleanliness of his aircraft, but had not said anything about the inner cleanliness, by which he meant the intake design. Although Dr. Seddon's lecture on air intakes for gas turbines must not be anticipated, he thought that the matter was vitally important; particularly as it was so very difficult, in the case of an intake, to provide a smooth finish internally as well as externally. A closed-in structure with two smooth surfaces was required. Would Mr. Clifton care to comment on this problem?

Reference had been made to the nasty problem of aeroelasticity, and he felt that they were approaching the stage of development at which they would have to add yet another perplexity, thermoelasticity, to the list of troubles. Thin, sharp edged, high speed wings would tend to distort at their leading edges, due to a rise in temperature when travelling at high speed, producing an effect on the aircraft similar to that arising from aeroelastic distortion.

He regretted that Mr. Clifton was quite so diffident about power controls; why not face up to the problem and have done with it? Several aircraft had now flown very satisfactorily with power controls, and in one instance the first flight had been made entirely with power controls in operation. Power controls had come to stay, and they might as well devote their energies to improving them rather than to considering auxiliary manual boosters.

In the illustration of integrally stiffened sheets the stiffeners were all lying in one direction; the stiffened sheet could be machined from a thick sheet, or extruded in circular form, then split and opened out. The objections to this method lay in the fact that when the sheet was formed to the shape of the wing surface the integral stiffeners would be twisted and would not lie along the generating lines. What was really required was a sheet of tapered thickness with the integral stiffeners converging towards the tip; longitudinal stiffeners would not appreciably improve the shear stiffness of the sheet and to postpone the inset of buckling both longitudinal and lateral stiffeners would be desirable. The manufacture of a sheet of this

type would present a difficult production problem, and possibly the only solution would be the development of large forging presses. Could Mr. Clifton say anything about the manufacturing possibilities for integrally stiffened sheet?

He wondered if he dare suggest that they must get rid of undercarriages altogether. The engine manufacturers had made their contribution by producing a very slim engine, but where should they put the undercarriage with its doors which were so prone to distort and open on inconvenient occasions? He felt that the time was approaching when they must consider seriously various ways of taking off and landing high speed aircraft without the use of an ordinary undercarriage.

Dr. H. F. Winny (Fairey Aviation Co. Ltd., *Fellow*): In Fig. 1 the author seemed to have chosen certain t/c ratios to apply to certain shapes. But he would have thought that in general, going to a delta wing, it could have associated with it a smaller t/c ratio for a fairer comparison of drag. The author had mentioned that the weight of the structure had been included, but still he would have thought that the smaller t/c ratio coupled with the delta wing would have shown up better on the overall drag at the higher Mach numbers, in the 1.0—1.1 range.

He wondered whether Mr. Clifton had been a little severe in assuming that the full temperature rise could take place on the acrylic resin hood; he would have thought that, by suitable positioning of the hood, the full temperature rise need not be taken on the acrylic resin, and that much of it would be left to be dealt with by the metal structure.

He agreed that the undercarriage might be dispensed with; it seemed that the smaller t/c ratios made the problem of the undercarriage urgent. Against that, there was probably additional advantage in the delta wing, because it made possible a larger chord at the root for housing the undercarriage, for the same t/c ratio.

E. G. Havard (Rolls-Royce Ltd.): He thought that a previous statement that the increased thrust of a reheated turbo-jet was obtained at much higher fuel flows than an unreheated turbo-jet engine, was rather misleading without due reference to perspective. It was true enough that increased thrust with reheat was obtained at a not inconsiderable penalty in fuel consumption when compared with the basic engine, but that was hardly a fair basis of comparison.

In order to achieve transonic speeds it seemed to him that it was first of all necessary to provide sufficient thrust per unit frontal area. Since a reheat engine provided an increased thrust within the same diameter as the basic engine it had obvious advantages in this respect. Furthermore, since reheat achieved an increase in thrust at virtually the same air flow as the basic engine, the gain in gross thrust achieved under static conditions would be considerably amplified at high speeds when net thrust, *i.e.* gross thrust minus air intake momentum drag, was the important quantity. Another point in favour of reheat in this respect was that it delayed the fall in propulsive efficiency with speed, to a speed value intermediate to that of an unreheated turbo-jet and an athodyd.

Having achieved the necessary speed they wanted to involve the least cost. As far as the aircraft volume was concerned a fair measure of this quantity appeared to be engine plus fuel weight. If this quantity were plotted versus transonic design Mach number, then the reheat engine would appear in a much more favourable light.

Mr. Clifton had asked for long thin engines in order to reduce body wave drag; reheat satisfied that requirement because the extra thrust was obtained in length as opposed to breadth.

W. J. Annand (Rolls-Royce Ltd.): His main interest was in the aerodynamics of the installation of the engines in aircraft and he referred to Fig. 5, showing the expected variation of entry pressure ratio (intake pressure recovery) with Mach number. If the simplest type of intake were used, just a hole in the front of the aeroplane, he did not see why the entry pressure ratio should be disturbed as the aeroplane passed through the transonic range, and in particular why there should be a discontinuity. What sort of intake had the author in mind when he stated that something curious might happen in that region, and was there any evidence that a discontinuity such as was shown in the graph could exist?

He had not been able to understand the lowest curve in Fig. 20, showing the loss of thrust due to air bleed and extraction associated with the internal engine cooling. If he interpreted it correctly, it showed a definite loss of thrust in transonic conditions and an actual gain in the supersonic. What

were the items covered by this curve, and what was the explanation of the change in its sign ?

The situation might not be quite so bad as the curves indicated, in that there were other means of protecting the structure than by cooling. Cooling was certainly difficult when the very air available for the purpose was at almost the temperature to which it was desired to cool, and it might be better to use shielding and lagging at hot parts, and a certain amount of pre-cooled air in particularly vulnerable parts.

T. L. Ciastula (Saunders-Roe Ltd.): There were difficulties in connection with dynamic stability, especially for fighter aircraft, and it was particularly difficult to eliminate them by flight research and other means because extreme accuracy of flight measurements was necessary.

Also, with very thin wings, it might not be possible to put fuel in them and, therefore, the ratio of yawing to rolling inertia could be completely different; normally it was 2.5 but might go as high as 5, with a continually increasing amount of equipment in the body of an aircraft. Some calculations had indicated that whatever they tried to do, a certain type of rolling instability at high altitudes in transonic flight seemed to come in all the time, particularly if the effects of product of inertia were included.

What general layout of an aircraft would Mr. Clifton suggest in order to obviate this difficulty in transonic flight at high altitudes ?

Power operation seemed to be necessary for some aircraft, and the best course would be to develop a reliable system which would work properly. His firm had developed and flight tested such a system for large aircraft with completely satisfactory results.

What did Mr. Clifton propose to do on a fighter aircraft with power-operated controls in the case of complete engine failure or complete combat damage to the engine ?

G. H. Dowty (President of the Cheltenham Branch, *Fellow*): It was particularly unfortunate that Dr. Redshaw had had to come to the Cheltenham area to sound the death knell of the undercarriage manufacturer !

He expressed appreciation of the fact that a main lecture of the Society had been delivered in Cheltenham on the 21st anniversary of the Branch.

The Council of the Society, at a recent meeting, had placed on record their sincere appreciation of the good work which had been done by Mr. N. E. Rowe, Chairman of the Branches Committee; and he was sure that he could speak for the Cheltenham and Gloucester Branch and for the members of the other Branches who were present on that occasion in saying how much they appreciated the work he was doing. Mr. Rowe had indicated his wish that there should be more main lectures to the Branches, and they all hoped sincerely that he would be successful in that respect. His work was appreciated by everyone.

N. E. Rowe: It was a great delight to him to visit the Branches, and it gave him great pleasure to see so large a gathering to hear a lecture in the Society's main series. Things were working out exactly as had been hoped. The Council had felt that one of the best things they could do for the Branches was to demonstrate that headquarters really did think about them, and that the best way to do that was to invite lecturers to come down to the Branches. It was stimulating and encouraging that eight Branches were represented at that meeting; that fact in itself spoke worlds for what the Branches were doing.

To work with the Branches cheered him; he had met a number of enthusiastic men, many of them young men, who were anxious to stimulate aeronautical thought and progress in their areas, which they were doing through the Branches, and to exchange ideas with those doing similar work in the country. When the Chairmen and Secretaries of the Branches met the Branches Committee in London every six months they had a most stimulating time, and he believed that the Branches had a great part to play in the general organisation of the Society. They were autonomous; they ran their own shows. They promoted discussions and stimulated aeronautical thought in their neighbourhoods, they encouraged young men to express their thoughts at the meetings, they helped to bring to the Society recruits of the right type, men who were keen to do something and to get things moving. Thus he felt privileged to work on the Branches Committee, and he hoped to carry on that work.

J. R. Ewans (*Associate Fellow*), *contributed*: The curves of Figs. 7, 8, 11 and 12 showed the serious reductions in the overall

elevator effectiveness in the transonic region; Fig. 11 in particular indicated that the solution of the all-moving tailplane recommended by the lecturer would still leave appreciable losses due to the tailplane and fuselage flexibility. (In the case of the former probably less than was shown in that figure.)

In view of this he would like Mr. Clifton's comments on the alternative solution of the tailless aircraft which was not mentioned in the paper. Considerations of longitudinal damping demanded a large root chord, and when combined with sweepback the plan form would necessarily be of the delta type, in which the trailing edge was more or less at right angles to the line of flight. With an elevator on the inboard part of the span the loss of effectiveness due to the aeroelastic distortion would be negligible. The aerodynamic loss depended on the particular values of sweepback and wing section, etc., employed, but Fig. 9 showed that this loss need not exceed 40 per cent.

MR. CLIFTON

Mr. Davies: He agreed that the use of a spoiler control in place of ailerons had possibilities, but one of the problems which would then arise would be the education of pilots, because it was highly probable that a control of that nature would feel and behave rather differently from an aileron.

As for the linking of the variable-incidence tailplane with the elevator by means of some arrangement whereby the movement of the elevator would cause the tailplane to follow it, he appreciated that it might be difficult to arrive at something which was satisfactory at low speeds as well as at high speeds, but he considered that the difficulty could be overcome. When they tried out something new they often found themselves up against difficulties; he felt that if they really got down to the problem and applied it to an aeroplane they would succeed in making it work, and he considered the advantages to be gained were well worth the effort involved.

Mr. Laight: In regard to canopy drag, the trouble about placing the pilot in a prone position was that he could not see behind him.

He agreed that the fuel consumption with reheat was high. But there were many people who seemed to think that even a rocket aeroplane might be used, and reheat fuel consumptions were modest in comparison with those of rocket motors.

Flutter was an extremely complex subject and required enormous calculations, and he had found it very difficult, within the compass of the paper, to fit in any adequate remarks on the subject. He must agree, however, that in the layout of a supersonic, or even a subsonic, aeroplane flutter must be considered very carefully indeed, for it was an important matter, especially in relation to control surface design.

Mr. Cuss: He was unable to say whether the American transonic range machines had met the type of trouble he had indicated as resulting from distortion.

The layout of the aeroplane which would show the effects indicated in Fig. 7, was one which he would describe as normal, *i.e.* it had a swept-back wing fastened to a fuselage, and a tailplane behind it, and the tail arm was a little less than two mean chords of the main plane. He believed the figures were based on a thickness/chord factor for the tailplane of 5 per cent.

Obviously, the answers obtained would depend very much on the structural arrangement. The results were susceptible to such things as thickness/chord ratio and aspect ratio. He did not suggest for a moment that one would accept as satisfactory the sort of results shown in Fig. 7, but they did indicate the type of results that could be obtained with an aeroplane of normal proportions designed according to ordinary strength considerations.

Regarding the integrally stiffened skin, if the ribs were not part of the skin it was necessary to fasten the skin to the rib somehow, and he considered that a skin which had the ribbing integral with it was better than one which had to be fastened to the ribbing by means of a row of rivets, because in the latter case, however careful the manufacture there would be a less smooth surface. As to the use of thick skin, it was necessary to design so that permanent buckling did not occur below the proof load.

Dr. Hilton: He could not say whether or not the delta wing was free from vices, because he had not flight experience of it. But so far as drag was concerned, according to the estimates upon which Fig. 1 was based, the delta wing did not come out best; and while they wished to eliminate vices—which

he supposed meant unpleasant control characteristics—nevertheless the fundamental problem was to make aeroplanes fly faster, and in order to do that they must achieve the smallest drag that was possible and deal with other matters in the best way they could.

Professor Redshaw: He was not certain that he quite understood the reference to intakes. Admittedly there was little mention of them in the paper, because they were so ignorant about them in the transonic range that there was practically nothing that could be said at the moment.

He agreed that thermoelasticity was undoubtedly a matter to which careful attention would have to be paid.

There was no alternative but to face up to the problem of power controls, but he was not very happy to design and build an aeroplane, costing a great deal of money and effort, and put into it a completely new idea on controls, and then ask the firm's chief test pilot to take it into the air and to see how it worked. They wanted to work up to it gradually, and that was probably why some of them seemed to be a little tentative in their approach. They were really hoping, as he had indicated in the paper, that with more aerodynamic knowledge and possibly a little luck they might even be able to reverse the trend towards power.

He did not agree that the integrally stiffened skin would have more shear stiffness if the stiffeners were provided in both directions; he believed that, if the stiffeners were properly designed as an integral part of the sheet, it could have as much shear stiffness with the stiffeners running in one direction only.

On the manufacturing possibilities, he knew only what he had read in various American journals, and he believed a standard sheet with stiffeners could be obtained in America. It should be possible to produce a stiffened sheet by rolling, with the stiffeners running in one direction.

He saw no difficulty in doing away with the undercarriage.

Dr. Winny: He agreed that the delta could have been designed with a smaller t/c ratio, but the aeroplane would have been heavier and the wing area shown on the diagram would have had to be increased. Whether or not that would have resulted in the delta showing superiority over other forms he did not know, as he had not investigated every possible arrangement exhaustively. It was possible that Dr. Winny was right, but his own opinion was that the delta would not show to advantage if it were thinned down further.

He was not entirely clear about the point concerning the temperature rise on the acrylic resin hooding, but he was under the impression that there was approximately 85 per cent. of the theoretical rise some way back from the front of the canopy. He believed that was Dr. Winny's point.

It was true that in the paper he had missed a point in not stating that, if the undercarriage were omitted, the aeroplane could be smaller and the drag could be reduced. When he had said, in reply to Professor Redshaw, that he could see no difficulty about dispensing with the undercarriage, his reason was that the carpet landing scheme had been tried out and it seemed a practical proposition; and the catapult could be used for take off. Therefore, if the Services would face up to the problem of providing the necessary equipment, they could do away with the undercarriage.

Mr. Havard: He agreed entirely with Mr. Havard, and referred to Fig. 4(*a*), in which the basic thrust factor was plotted against reheat making out a very good case for the reheat engine. If they wanted to fly at a Mach number of 1.3 at ground level without reheat, they would want about $7\frac{1}{2}$ times the thrust of the present Avon or Sapphire engine, but if they could reheat to 2,000° they would need only $2\frac{1}{2}$ times the basic thrust of the engine without reheat. In other words, to fly at $M=1.3$ they wanted the equivalent of $7\frac{1}{2}$ engines without reheat, but only $2\frac{1}{2}$ engines with reheat.

Mr. Annand: Regarding the bottom curve in Fig. 20, there was an addition to the thrust at low Mach numbers, and a loss of thrust at higher Mach numbers. He believed the explanation was that under subsonic conditions the internal air flow acted as an engine, just as under certain conditions with the piston engine the radiator acted as an engine; they obtained some thrust out of the radiator duct owing to the heat put in. But at higher speeds the loss of thrust in the actual jet preponderated, and the net result was that at the higher speed there was a loss.

Mr. Ciastula: He had already expressed his views on power operation. They would prefer to avoid power operation if that were

possible, because of the problems involved, but one could not say that it could be ruled out. They were forced into it, and possibly would arrive at a control system completely operated by power.

In case there should be a failure of the power control system, reliance would have to be placed on hydraulic accumulators to provide the energy for the hydraulic system and electric batteries to give the electricity supply to bring the aircraft safely down in the emergency.

Mr. Ewans: It was true that both tailplane and fuselage flexibility might give large losses in the effectiveness of the fore and aft control and the layout of the aeroplane must be considered in the light of such factors.

Regarding tailless aircraft of delta plan form, he thought that the elevator control forces on that type would be larger than with a tail, in spite of any gain in effectiveness, due to the increase in elevator size necessary on the tailless aeroplane, consequent upon the short "tail" arm.

*Production Research on Aircraft**

by

L. E. BUNNETT

1. INTRODUCTION

In choosing a title for this paper, the words "operational research" might have been preferable to "production research" in the sense that "operations" refer to the strategic deployment of all the forces at the disposal of management, but to most engineers they would imply research into manufacturing processes only.

The title first chosen was "Production Costing of Aircraft," but this was discarded because it might have conveyed the impression that it was addressed solely to accountants whereas it is primarily intended for engineers who are already—or will be in the future—responsible for some part of the management of aircraft production.

2. PRODUCTION RESEARCH

Production research is a broad term, whereas production costing is not, and although the present argument is largely based on costs, it is concerned with costs in so far as they are a measurement of TIME, and TIME is the essence of production research.

High productivity is the object of production research, "productivity" being simply defined by Dr. T. E. Easterfield[1] as "output per unit of input," and in practice the unit of input is essentially man-hours or the time occupied in human application. This is *ultimately* true of all input, for material costs or overhead costs resolve themselves in the last analysis into the expenditure of labour or time. In this concept the word "labour" includes all labour: both direct and indirect, or productive and non-productive.

Production research is the art of weaving high productivity and the warp of the cloth is TIME.

Productivity is frequently increased by invention. Hundreds of processes and methods which are employed in the manufacture of aircraft have sprung from the inspired genius of engineers who have taken thought and then by infinite pains have contributed a new way of production. Yet the Journal of the Royal Aeronautical Society contains but few references to this aspect of the making of aeroplanes. A search through the Journal reveals that there has been about a score of papers in as many years which concern themselves with production or construction, while there is scarcely any reference to the organisation and management of an aircraft factory.

Apart from invention as a means of raising productivity, production research may be divided broadly into two parts, both of which depend largely upon the analysis and application of past experience. For present purposes these two zones of research may be described as

(*i*) Research into manipulation

(*ii*) Research into organisation of manufacture.

3. MANIPULATIVE RESEARCH

Manipulative research covers, in general terms, the work which is done in planning offices and jig and tool departments. It is the kind of work which is done in the workshops of the National Gas Turbine Establishment and the Production Engineering Research Association. It is usually specific in origin in an endeavour to solve some particular manufacturing problem and calls for the employment of practical engineers coupled with some measure of that

* A Lecture given to the Graduates' and Students' Section on 6th November 1951. Mr. Bunnett is an Assistant Director in the Ministry of Supply.

inventive genius already mentioned. It includes all research into new methods of production and cognate technological problems such as concern feeds and speeds or cutting fluids.

It plays an important part in making production possible and in increasing productivity; a part which becomes the more important as the aircraft designer increasingly demands more complex structures.

Professor J. V. Connolly sounded a warning in this connection when he said that there is a point beyond which technical improvements in design, at the expense of ease of production will be of no use.

Production research of this kind is going on continuously in all the larger aircraft firms but its cost is usually recovered through the application of overheads so that it is difficult to judge how much is spent on it. There is certainly much less technical research on production than there is on design.

It is not proposed to pursue at length this part of production research which deals with manipulation except that it will be seen later how the cost office provides at every point the measurements of time which are indispensable in assessing the merits of new methods. Instead, attention will be concentrated on that part of production research which has been called the analysis of organisation and manufacture.

4. ORGANISATIONAL RESEARCH

Practically no deliberate attempt is yet made in this country to conduct regular and consistent research in this field, at any rate in its special application to the manufacture of aircraft. Day-to-day organisation and manufacturing problems are frequently tackled by making *ad hoc* decisions based on the individual judgment and experience of the management. Often these are no solutions of the problems at all, and they result in unbalanced production, unrecorded but excessive waiting time and the eventual failure to meet programmes.

Failure, when it becomes obvious and imminent, leads sometimes to the advent of consultants who, coming in from outside, are able to examine the organisation objectively and impartially and often to effect a cure: but consultants should not be called in like doctors because a factory has grown diseased; their proper sphere is to be called in as a deliberate part of the progressive policy of a company to augment the company's own staff when some special problem of, say, expansion, needs the intensive application of specialist experience for a short term.

In normal times a factory should contain within itself all the necessary elements of good health, good layout, and good organisation.

It is taken for granted that the firm's designer must go through a long period of training before he is entrusted with the job of creating a new aeroplane. It is equally important that the men who produce it should be fully trained in their specialist fields, but their training must include sufficient knowledge of the whole organisation of factory management.

5. INTEGRATED TRAINING

There are two main groups of a factory staff concerned with the management of production; there is the "formulating" staff which includes engineers dealing with planning methods, tool design, estimating, time-study, motion-study, rate-fixing, and shop supervision; and there is the "analysing" staff consisting of the accountants dealing with the profit and loss accounts, the payment of wages and other expenses, the recording of times and costs, and the making of analytical returns from a study of which management is able to make policy decisions.

These two groups are dependent upon each other in great degree and efficient production depends largely on their efficient integration, yet how many of the members of either group have any training in, or real knowledge of, the work of the other? How many accountants have had specific training in the job of controlling costs in an aircraft factory or have had any practical knowledge of aircraft production? How many planners, estimators, or rate-fixers have had any specific training at all in their particular subject, and are there any who have had a business training and a knowledge of factory economics, costs, and accounts? Isn't it often the case that a bright young man, having come out of his apprenticeship, suggests a new method, and is transplanted into the planning office? In the planning office he will be called upon every day to make

comparative decisions between one tool or one method and another, and yet he may know nothing of labour costs and capital costs.

There is a tendency towards a more intensive specialised training both in the United Kingdom and in the United States, although in the United Kingdom the facilities for training industrial accountants and methods engineers are still deplorably sparse. Specialisation, necessary and desirable as it is, carries within itself the evils of disintegration and there is a growing need for adequate general management training to correct the super-subjective specialisation in the engineering field. It is so easy for the accountant to feel that a perfectly presented profit and loss statement is the object of his firm's existence and for the time-study engineer to consider that the operators are paid to provide him with interesting cases for his observation.

Both of these fields, accountancy and executive engineering, are popular and normal grounds for the breeding and recruitment of managers, but without a proper understanding of each other's work and contribution to the running of the factory they must, when they come to a position of control, incline towards making policy decisions which are biased and encased by their specialist experience.

6. EDUCATION FOR MANAGEMENT

In the United States there is an increasing move towards correcting this weakness, but even there the opportunities for education in management are limited.

Harvard University has a Graduate School of Business Administration which runs a two-year course and turns out six hundred trained executives each year. Of this number it is interesting to note that approximately twenty-five officers are sent to this course each year from the United States Air Force and the Bureau of Aeronautics. These men are assigned on regular duty and take up service appointments on graduation.

In addition, according to Assistant Dean John B. Fox, between ten and fifteen graduates enter the aircraft industry each year.

Some of the other universities in America have followed Harvard in conducting similar post-graduate two-year courses.

There is also at Harvard a twelve-week Advanced Management Course for executives and there are usually a few men from aircraft firms attending this at their firm's expense. The United States Government also sends to this course flying officers who are drawn from executive civil service appointments such as the contract-placing departments.

The Universities of Pittsburg and Pennsylvania in the United States, and of Western Ontario and Toronto in Canada,[2] provide further education in administration especially for business executives on the lines of Harvard.

In Great Britain, the Administrative Staff College at Henley-on-Thames runs twelve-week courses.

Also, at the unique College of Aeronautics at Cranfield, there is a Department of Aircraft Economics and Production—the only school of business administration in the world specifically intended to train aircraft executives.

The syllabus includes *inter alia* administration, personnel management, cost accounts, production control, planning, estimating, time-study, and work measurement.

It is training of this kind which paints the broad picture of production research and will furnish aircraft engineers with an analytical approach to the future problems of management.

Graduates from the schools which have been mentioned are well fitted to take appointments as assistants to managers, where without executive authority they can carry on production research untrammelled by routine responsibilities. They can bring to notice the need for improvements and point the way towards the methods of making them.

This is the field of research to which special attention is given here and the remainder of this paper is devoted to some of the ways and means by which it may be explored.

7. TIME SAVING

It has already been said that the saving of time is the essence of production research and it would not be an overstatement to say that all production management is directed towards the saving of time. It is therefore essential for the production engineer to have in his hands an instrument for measuring the

time expended in various ways in his factory and this instrument is provided by the cost accountant.

8. COST ACCOUNTANCY

This is a most valuable instrument and one that is neglected too often. It is to be hoped that, as accountants come to have a better technical appreciation of the problems of production and the engineers learn something of the possibilities of cost accountancy, as well as its limitations, it will eventually serve its true and proper purpose.

There is a tendency in some aircraft factories to look upon the cost office as an expensive evil, necessary only to provide government accountants with information. In such factories the chief accountant will naturally arrange his records in such a way that they satisfy official requirements and no more; whereas, in those factories where the full value of cost accounting is appreciated, figures will be produced on which the management can and will take action on every day of the year. It then becomes the compass by which Production is constantly steered to the delectable shores of High Productivity.

It is assumed that the voucher records which originate in the factory, such as job cards and stores requisitions, will be accurate and in sufficient detail for proper analysis to be made. They may be historical bookings or "standards" against which deviations may be noted.

In general the cost accounts will be analysed in two ways:—

(*i*) Functional analysis; providing returns of expenditure against departments or trades or against distinct classifications such as "waiting time" or "scrap," and

(*ii*) Product analysis; providing returns of job costs or product costs.

These returns, which should be made at regular and short intervals, may usefully include any or all of the following:—

Piece-part costs
Component or unit costs
Batch costs
Total non-productive hours
Total productive hours
Total waiting time
Waiting time analysed under reasons
Productive hours worked on piece-work
Productive hours worked on day-work
Productive hours worked on lieu bonus
Hours spent on rectification
Hours spent on scrap
Additional allowances made by rate-fixers
Average bonus earnings in each shop
Lowest and highest individual earnings
Possible weekly hours
Average weekly hours worked.

Such returns will provide the young assistant to the manager with pointers on which he will work, and analyses of the product costs will provide essential information on which forward planning and policy may be based.

9. FORWARD PLANNING

The initial figure required for all forward planning work is an estimate of the total man-hours of the product and historical records of past achievements on different types will be essential means of arriving at it. If the records provide figures for different batches it will enable "learner" curves (or T. P. Wright curves) to be built and the future programme can then be arranged, as far as possible, to bring in a new type while tailing off an old one without waste of labour.

This problem has been dealt with by G. R. Edwards[3] and, although he was mainly concerned with the utilisation of the design office, the same considerations apply to production.

No budgetary control or reasonable forward planning can be carried out without an intelligent estimate of the labour required for the new production and historical records are the only bases on which such estimates can be based. It is desirable, therefore, for these to be as comprehensive and detailed as possible. Analyses are frequently made of man-hours per pound of structure and calculations on a time/weight basis may paint a valuable picture of the future if accurate weight estimates are available. As, however, overall weight estimates originate in the design office from a summation of the estimated weights of individual components, the production labour estimates will be more accurate if they are based on time/weight ratios from historical records, component by component.

It should be remembered, particularly with airframes, that improvements in design are

frequently introduced to reduce weight and that this usually entails additional expenditure of labour. If it costs x man-minutes to make a sheet metal diaphragm of y lb. it will cost more than x man-minutes to make the same diaphragm pierced with lightening holes and it will now weigh less than y lb.

Analysis of the ratios of different trades will provide information on which to base future labour requirements. The percentages may differ considerably for various products, as the following figures show:—

	Airframe per cent.	Aircraft Engine per cent.
Machining and mechanical processes	20	60
Detail fitting	40	18
Assembly, erection, and test ...	40	22

Figures in such general terms should be readily obtainable from the cost office but if the information can be supplied in greater detail so much the better. An accurate analysis of labour bookings to different classes of machine operations makes it possible to plan a machine shop layout and machine tool requirements on a new type of product, but of the same breed, before even any detail drawings have been provided.

10. ESTIMATING DEPARTMENT

Apart from the historical information supplied by the cost office, the estimating department must be relied upon to provide assessments of the future. It goes without saying that the estimators should have full access to all cost office records and in addition will automatically receive copies of all time studies (if these are produced by a separate section) and of time allowances from the rate-fixing office.

The estimating department should be used a great deal more than is frequent in practice. As well as performing their normal function of providing forward estimates of cost for quotation purposes and planning, they can provide comparative estimates on which day-to-day decisions can be based in the manager's office, the main design office, the jig and tool office, the planning department and the shops.

The choice between a capstan and an automatic when both machines are available should not be left to the experience of the planner. There is a "break-even" point in the quantitative scale at which, taking into account machine depreciation, overheads, tools, labour setting and labour operating, the cost per unit would be the same for either machine, and either side of which the decision is clearly in favour of one as against the other. Most engineers unfamiliar with such comparisons are surprised at the smallness of the batch which can often be produced on the automatic lathe in economical competition with the capstan.

No jig and tool should ever be authorised until, and unless, an estimate is submitted showing its probable cost and the unit times which are expected to be taken in performing operations with it. The loading of jigs and fixtures sometimes occupies a greater time than the actual operation itself and in such cases ingenuity in improving the loading element becomes of major importance.

In an example noticed on turbine compressor blades the actual cutting time was three seconds and the time for loading and unloading was fifteen seconds. The use of cam action or pneumatic clamps would have reduced this time to no more than the cutting time.

Tool designers should realise that their job consists in doing more than providing a means of producing a part. They should consider the economics and provide means of producing it in the least possible time.

11. COMPARISONS OF ESTIMATES AND ACTUALS

The first step to be taken in organisational research is to secure an accurate estimate of the unit times of production and, when production has begun, comparisons of the "standards" and the "actuals" will indicate the direction which investigation might take. Items on which there are large deviations are obviously those on which attention should be concentrated.

The early batches on the production of a new type will not be expected to be within the estimates and the comparison can be made with due allowances from reference to a "learner" curve.

This approach by comparison will usually lead to the need for manipulative research to improve the methods on specific components.

12. TIME CYCLE

Forward planning of production is often too optimistic and attempts are made to fit detail planning, machine loading, and assembly into an impossible structure. This inevitably leads to constriction and shortages. The shortage of a single small part is in fact a failure to meet a programme, and it is the accumulation of shortages which prevents aircraft getting into the air. It is impossible to cure this by concentrating effort on the assembly and erection shops. Sausages are made by forcing the meat into the machine and the sausages come out without difficulty. By concentrating on the supply of complete sets of parts the production of complete airframes or aircraft engines can also be easy.

Forward planning of programmes is based on an accurate application of labour to the calendar. If an accurate estimate to make an aeroplane is 50,000 man-hours it is still quite impossible for 50,000 men to produce one aeroplane in an hour, and a further estimate must be made of the time-cycle required for manufacture. It is often on this factor that promises are broken. The time-cycle required for the whole is that of the part having the longest cycle itself, and it must include, after drawings are available, time for ordering and procuring materials, designing and manufacturing tools, manipulating, inspecting, assembling, and despatching. Vital though this datum is, there are still some firms who are unable to state with certainty what the actual time-cycle of their existing production is and are consequently adrift when it comes to offering a programme for the future. Yet, owing to the need for maintaining the identity of materials, it is usually easy to obtain from inspection records the date of entry and despatch or flight.

Even during the peak production period of the Second World War the actual time which expired between forgings coming into a factory and becoming airborne was, on one occasion, more than twelve months, and yet the firm's programme was based on a cycle of four months.

13. UTILISATION EFFICIENCY

Another factor necessary to the formulation of a programme and one on which it frequently fails is the utilisation factor, applied to basic estimates, both of men and machines.

The Joint Committee of the Institute of Cost and Works Accountants and the Institution of Production Engineers has said that " it is clear that machine utilisation is low and if this were improved it would make a significant contribution to increased productivity."[4]

Unfortunately few cost office returns provide information by which this can be accurately assessed and odd minutes of machine idleness never get recorded at all. Observations made of the physical position in the shops are the only way of obtaining this. Those observations should be made throughout the whole of a working day and repeated if there is any doubt of the sample day being representative.

14. MACHINE SHOPS

At a time such as the present day when many machine tools are in desperately short supply it is usually more important in the machine shop to analyse machine than labour utilisation and one observer should be allotted to about six machines. Observations should be made throughout the working day and a record made of every minute that the machine is not in process of being loaded, unloaded, or actually cutting or producing. The reasons, during every minute of time when the machine is not so used, must be recorded and at the end of the day the results should be analysed under these headings.

The following analysis on eleven capstan lathes is typical of many hundreds of such observations made during the war.

	Per cent
Operating	45
Not utilised	23
Breakdown	10½
Setting	10½
Waiting for setter	½
Operator missing	2½
Clean down	1
Wait inspection	1½
Not working	1
Waiting for tools	½
Tea break	4
	100

Programmes are often calculated on the basis of total machine hours per aircraft, total number of machines to be installed, and the total weekly hours during which the

machines will be available, *i.e.* manned. This is adjusted by a figure of 75 per cent. or 80 per cent. efficiency. Too often it is forgotten that the required production will not need the full utilisation of some of the special machines for the whole working week and the overall utilisation factor is more often in the region of 40 or 50 per cent.

It is usually possible to load each class of machine separately and setting times can be estimated and allowances pre-determined according to the most economical batch size to suit the programme. Tea breaks are also a known quantity and can be allowed for exactly. Excessive idleness around tea breaks, voluntary and involuntary absenteeism, and all the other reasons for non-utilisation are inefficiencies which good management will seek to reduce to a minimum.

15. LABOUR UTILISATION

Observations in fitting, assembly, and erecting shops are made by counting, from some suitable fixed point, the number of operators who are working, walking, or standing. A space which normally encloses some fifty operators is the maximum that should be attempted by one observer.

The count should be made every three minutes and the results analysed at the end of a complete day.

In a fitting shop which is well organised it is possible to get a labour utilisation factor of over 90 per cent. of the available hours, but this is exceptionally high and figures as low as 50 per cent. are common though obviously unsatisfactory. If "walking" accounts for a large part of the waste time an examination of layout is indicated to check the lines of work flow, the position of stores, time offices, or lavatories. If "standing" is the offending item then the incentive scheme may be suspect, or shortages of supplies, instruction, or inspection.

These observations have a twofold purpose: first to check the factors used in forward planning, and second to reveal inefficiencies.

It is most essential before making observations of any kind, in the shops, to explain to the work people exactly what it is intended to do. When this course has been followed there has never been the slightest ill-feeling engendered over many hundreds of observations; on the contrary, by showing the results to the operators useful improvements have often been suggested.

Another method of analysing labour utilisation is to attach an observer to a typical operator throughout the day, or from the start to finish of a job, making what is in effect a time-study of the operator's time and not of the operating time.

An observation of this kind, made in a large airframe factory during the war, indicated that individual jobs in the fitting shop were taking over half an hour to start. There were some 10,000 jobs issued to the shop every week and it was disturbing to realise that some 5,000 hours were being wasted each week, equivalent to the whole time of approximately one hundred employees.

By providing adequate copies of drawings and small tools, and using labourers to collect beforehand kits in tote pans which included the job-card, the drawing, the material and the special small tools and gauges that were necessary, the average starting time was reduced to a matter of minutes and a large amount of skilled labour time, which had previously been wasted, was thus used on productive work.

16. WAITING TIME

Although waiting time is usually recorded and the cost office make returns of the amount of it, it is customary for it only to be booked after a stipulated time has elapsed of ten minutes or so and therefore odd minutes of time can be lost throughout the day which are unrecorded. It is only by observations and research *in the shops* that these odd minutes can be tracked down and their causes eliminated.

It is a mistake to think that because operators are on piece-work any time they waste is their loss alone. The average British workman is prepared to work while he is in the factory and if he is working against a set target he has an incentive not to waste time, but it is equally in the interest of the firm and of the nation for him to be so well served with materials, tools and conditions that it is possible for him to give of his best. A wasted minute may lose the operator a halfpenny or a penny but it will lose the firm much more than that in overhead costs. It might be a useful exercise for the chief accountant to

work out the cost of the average wasted minute and inform the management on this point.

If these minor inefficiencies which cause odd losses of minutes are consistent, the rate-fixers are soon perforce persuaded to make allowances for them in their rates.

17. FACTORY LAYOUT

When a motor-car manufacturer embarks on a programme he is usually able to plan an exact production layout where everything flows through with a minimum amount of waste.

Aircraft design is far more fickle and when a new type is produced it frequently calls for new methods, new machine tools, and a re-shuffle of equipment. Even during the life of a type, modification may cause similar dislocation of layout.

Shop layout should therefore be constantly examined and this can be done by taking a plan of the shops and tracing on it the devious paths and routes over which each part travels. When these cross and recross there is need to look for a re-arrangement.

It may be that in the course of time the flow in a shop has in effect been completely reversed and a sub-store which previously served it efficiently from one end should now be moved to the other. These things, obvious as they seem when spotted, are constantly overlooked, and it is only by carrying on continuous research and making deliberate analyses that they come to light.

Tracing the course of one or two individual parts from their entry into the factory to the time that they are airborne will often reveal ridiculous waste movement.

In one factory it was the practice for all parts to be moved into a central store after an operation on them was completed. Thus a blank for the press shop would go to the store and out again to the fitting shop to have a hole drilled in it and back to the store. Meanwhile a turned pin from the machine shop would go in to the store. Then the pin and the drilled blank would go out to the assembly shop to be joined together and back again to the store until wanted by erection.

By installing small sub-stores in the different shops and routing the parts directly to them the number of movements was cut by 40 per cent.

In another factory it was found that most individual parts found their way into each of seven stores before they were completed.

Stores are only places for keeping things in safety. Keeping things is a way of locking up money and is completely non-productive. Stores should be indulged in only from sheer necessity. Ford's at Dagenham have no stores of finished parts other than the parts travelling along the conveyors. It was reported recently that the Northrop Company of America[5] have abandoned enclosed stores and are now storing materials in the actual production line.

18. MOVEMENT OUTSIDE THE FACTORY

Wasteful movement may take place in regard to sub-contracts. It is quite a common practice for raw material to be brought in to the parent factory where it is inspected, re-packed, and sent off to sub-contractors. There is no reason why it should not go direct to the sub-contractors; a number of firms arrange with their suppliers to send it direct.

Government departments are not usually credited with much sense of economy but imagine the waste and confusion which would be incurred if all engines, propellers and other embodiment loan parts had to be delivered to Millbank or a stores depot before they arrived at the aircraft erector.

19. WASTE MATERIAL

As already said, material wasted is really labour wasted, for its value or cost is derived from the labour required to produce it.

It is of the utmost national importance to save material, because so much of it is imported, and there is a good deal of scope for research in this direction. It is estimated that in the United States about 15 per cent. of the original weight of all steel and about 5 per cent. of all castings become scrap during factory processes.[6] To decrease the amount of scrap by one per cent. may not seem very important but it means a complete aeroplane or an engine or a propeller or a starter when a batch of a hundred has been made.

The reduction in allowances which have to be made for parting off or cutting from sheet directly affects the amount of material

scrapped, and good tools, good operation training, quality control, and other good practice can do much to reduce the cost of scrap.

It should be remembered that labour spent on scrapped work or on rectification is just as much time lost as if the operator were on waiting time and is just as expensive.

20. OVERHEADS

What can be done in the shops can also be done in relation to overheads and, as these often account for half the cost of an aeroplane, the scope for eliminating waste is greater than on labour or materials.

Many American firms employ what they call internal auditors who do overheads research in the offices and factory services in much the same way as has just been discussed.

Pieces of paper cost money to produce and to disfigure and these, reproduced in large quantities, find their devious ways into locked drawers and into dusty files on high shelves. They are often as great a brake on production as a faulty method or an untidy shop.

21. OTHER AVENUES OF RESEARCH

There are many other avenues of research through which improvements, in colour schemes, factory lighting, and so on, may be introduced and any of which may tangibly increase productivity. In fact research may usefully be pursued on any matter which affects the factory, enabling policy to be framed, not on a "hunch," but with reasonable certainty as to the results. It is impossible even to touch on every subject within the limits of a single paper.

22. THE POSSIBLE RESULTS OF RESEARCH

What can be got out of organisational research of the kind which has been considered?

The efficiency of a heat engine can be considered in terms of thermal units which are connected with useful work. The efficiency of a factory can be considered similarly if terms of measurement and expression can be found. Much thought is now being given to this problem of measuring productivity but no completely satisfactory solution has yet been found.

Both selling price and sales value are misleading yardsticks as they include, of necessity, the average inefficiency losses of an industry, and comparison between two industries is at present almost impossible. Even between two factories making the same product there are so many local deviations that comparison may be misleading.

Comparisons of man-hour productivity, even when a satisfactory formula is developed, restrict the analyst to the labour element, though they have the merit of being capable of international examination, since time measurement is internationally constant.

Fiscal measurement has the twofold disadvantage of making international comparison difficult and historical comparison impossible. Money depreciates in value continuously, though not consistently, and it is impossible to compare the efficiency of producing a £2,000 pre-war with a £5,000 post-war aeroplane.

For day-to-day use within a particular factory, however, it may be possible to apply the heat-engine analogy, treat the expenditure in pounds sterling like the fuel consumption in British Thermal units, measure the losses, and express efficiency as the ratio of expenditure to expenditure minus its losses. Direct labour and material can be examined intelligently in this manner.

In the case of labour the "time standards" must themselves be analysed and only that element of time which is occupied by producing useful work can be counted. It is probable that this will include a loss of something like 60 per cent. of all money spent in labour.

With material, all scrap and rectification costs are losses and a waste of something of the order of 20 per cent. occurs.

If a typical breakdown of the expenditure of £100 could be produced, it might be of this order:—

Labour	£20	loss 60 per cent. or	£12
Material	£30	loss 20 per cent. or	£6
Overheads	£50	assume combined in same proportion as labour and material	£18
	£100		£36

The probable efficiency is therefore $100 - 36 = 64$ per cent.

These figures are not intended to suggest that efficiency in aircraft production differs from that of other industries. They are not offered in any sense as being accurate,

although they are almost certainly optimistic, but as an indication of the enormous scope there is to improve efficiency and increase productivity. If a firm which turns over a million pounds a year is in fact spending £360,000 which is producing nothing, then an improvement of only one per cent. would save £36,000, and it is obvious therefore that production research of the organisational kind considered is very much worth while. Since increased productivity is regularly resulting from organisational or operational research of the kind which has been described, it is highly probable that this is the most fruitful field for improving our national productivity.

If, by taking a little trouble, every one who works in a factory can be producing for a little nearer to 60 minutes in each hour, if for every twenty shillings worth of material purchased something nearer a pound's worth flies away in finished aeroplanes that have passed inspection, a step further will have been taken towards that goal of increased productivity for which the British nation is so desperately striving.

Full employment has eliminated the terrible national waste of men and women without jobs. Full utilisation will eliminate the waste that still arises in incredible amounts when they are at work.

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*Some Operating Problems of Future Transport Aircraft**

by

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1. INTRODUCTION

To judge by the newspapers, the day of the turbine powered transport aircraft is already here. This is not to say that the piston engine is no longer required; probably it will be in use for many years to come, particularly for small aircraft, but new major designs must certainly be planned so as to take advantage of this revolutionary new form of prime mover.

Since the design and manufacture of a modern transport aircraft may take anything from four to six years, airline operators have had to anticipate actual prototype aircraft by theoretical investigations on turbine transports. This is particularly the case with the British Overseas Airways Corporation, which, in 1945, was the first operator in the world to order such aircraft. In order to reach essential decisions on numerous aspects of design, B.O.A.C. carried out a continuous series of studies. These were first directed towards gaining a knowledge of the characteristics of such aircraft. The results have been embodied in a paper read in 1949 at the Second Anglo-American Aeronautical Conference and those portions dealing particularly with the operating characteristics have since been reprinted.[1]

The purpose of this paper is to present the companion picture of the problems ahead in the actual operation of these future aircraft, particularly those with gas turbines. It will not be exhaustive, but it will give some food for thought. The diagrams are taken from the paper presented at the Anglo-American Conference.[2]

The paper is divided into three parts:—

(*i*) to consider the commercial application of these aircraft—to see how their higher speed can be used, and so on.

(*ii*) to discuss some of the operational problems that are likely to arise.

(*iii*) to list those aims and principles by which the manufacturers and the operators should direct their efforts.

2. COMMERCIAL APPLICATION

Any increase in cruising speed, however small, is of some advantage to the operator if it leads to a higher block-to-block speed. However, this increase in speed usually costs money and will not always pay. It will not unless it permits the aircraft to do more work in a day, and an increase in the rate of work can only be achieved in one of two ways: either by increasing the number of flights, or by increasing the length of the route.

There is a limit set to either process by the habits of the travelling public, who can only be induced to accept arrivals and departures outside normally convenient hours by offering cut rates, such as the £11 fare to Paris for departures after 10 o'clock at night.

The London-Paris route has often been quoted as the most natural air route in the world, competing as it does with surface transport normally involving at least two

* This paper was given as a lecture, first to the Bristol Branch of the Society, on 16th January 1950, and then to the Reading and District Branch, on 15th March 1950, and is published now as being of general interest. Although the conclusions given in the paper were almost entirely derived from the theoretical studies made by British Overseas Airways in preparation for their new fleets of turbine aircraft, few statements would have to be modified as a result of the subsequent two years of practical experience.

Mr. Dykes was Chief Engineer (Development) with B.O.A.C. until he relinquished this appointment at the end of 1951.

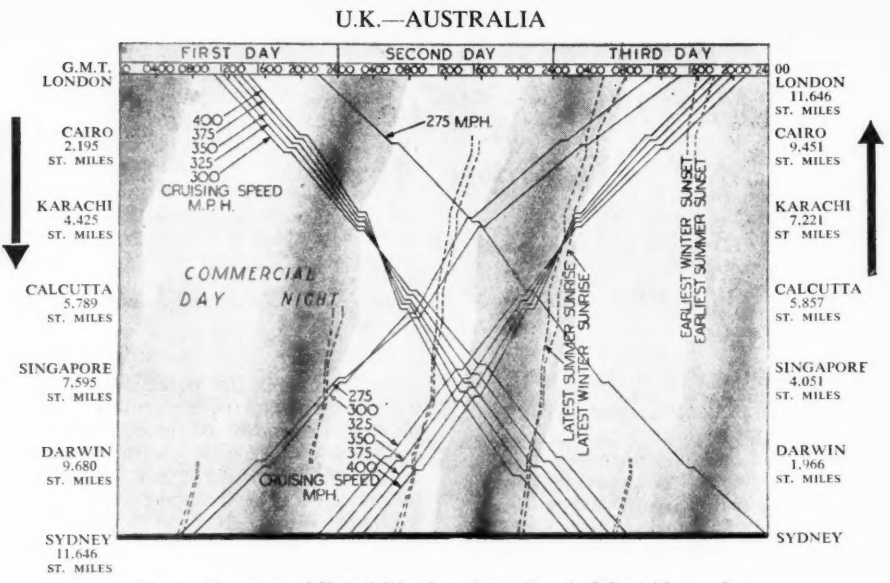

Fig. 1. Variation of United Kingdom-Australia schedules with speed.

changes, and always a sea crossing which can be most unpleasant. Before the Second World War the fastest schedule was 70 minutes, achieved with aircraft whose cruising speed was 195 m.p.h. The fastest timing now quoted is 75 minutes, although the cruising speed is 40 m.p.h. faster; while the increase in time is partly due to the use of different airports with an increase in the distance flown, it is mainly due to increased complexity of airport and traffic control because of the high density of traffic. To reduce the schedule to one hour dead, a further increase of 70 m.p.h. is necessary in cruising speed. At the present speed of 235 m.p.h., one aircraft can be used for three return flights in the space of a convenient working day. The speed must be increased to no less than 420 m.p.h. before the aircraft can be used for four return trips in the same length of time and with the same time on the ground. Therefore, for this route, the advantages gained from moderate increases of speed above 235 m.p.h. are purely competitive and not directly operational.

On a long trunk route, it is necessary to consider the arrival and departure times at all places along the route. Fig. 1 shows the results of a study of the best speed for operation of the United Kingdom-Australia route. The most practical time tables have been indicated for a series of cruising speeds from 275 to 400 m.p.h.

As far as possible, arrivals and departures have been planned within the "Commercial" hours between 8 a.m. and 9 p.m. local time, with the further proviso that departures from London are not made before 10 a.m. in order to permit intending passengers to reach London from the suburbs. A cruising height of 30,000 ft. has been chosen to represent future operations with gas turbines. The time tables have been drawn up for Northern Winter, with "target" stops of 45 minutes at each place, which are admittedly much shorter than present practice.

At the lowest speed of 275 m.p.h., it is necessary to spend three nights and two days out to Australia, but if the cruising speed can be increased to 300 m.p.h., this can be reduced by one night which is a great improvement. In the reverse direction, the elapsed times are longer because of the steady headwind, but the 11-hour time differential between Sydney and London reduces the apparent duration at 275 m.p.h. to two nights and two days. 325 m.p.h. is the critical speed in this direction, allowing a rearrangement of the time table and thus operation in two days and only one night.

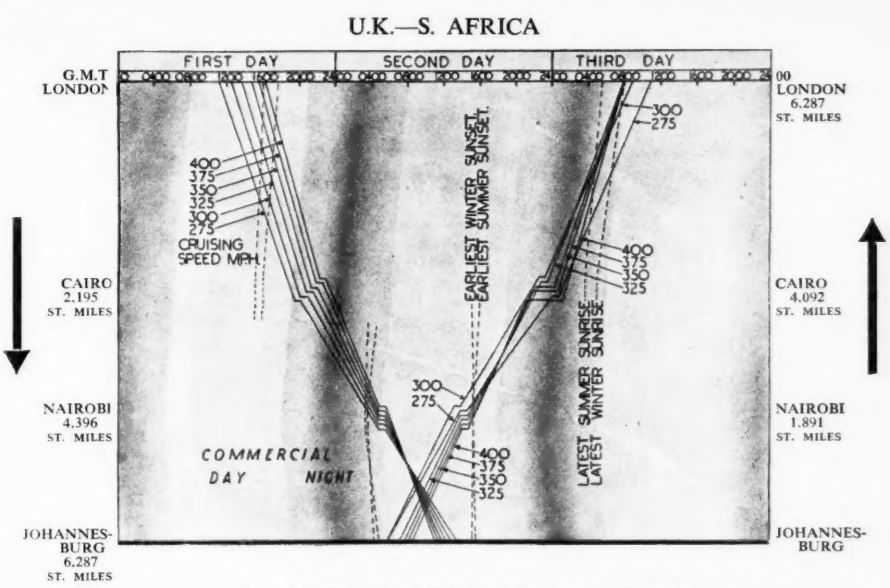

Fig. 2. Variation of United Kingdom-South Africa schedules with speed.

This is the longest route in regular operation in the World, and if only one night must be spent on the way, it is the author's belief that bunks will find less and less application in future.

In both directions of this route, therefore, every increase in speed yields a decrease in schedule time. The cost will have to be balanced against the competitive advantage gained. Occasionally operational limitations prevent full advantage being taken of a higher speed. For example, in common with many places within 30° of the equator, Nairobi and Johannesburg are often covered with low cloud in the late afternoon and early evening. While this is no great hardship for local operations, long distance operations can be completely dislocated because of the length of time between the forecast on which the decision has to be made for any particular flight, and the probable time of arrival. Until improved radio facilities are provided, it is necessary for about half the year to avoid scheduling into either Johannesburg or Nairobi at these times of the day, *i.e.* between about 4.30 p.m. and 9 p.m.

Figure 2 shows the similar analysis for the United Kingdom-South Africa route. Neither operational limitation has any effect in the outbound direction, and any cruising speed within the range 275-400 m.p.h. permits a satisfactory schedule. In the reverse direction, because of the operational limitation at Nairobi, excessively early morning arrival at London can only be avoided at cruising speeds of 300 m.p.h. or over, by introducing stop-overs at Cairo which absorb up to 75 per cent. of the reduction in flight time. The net effect of the increase in cruising speed is therefore only the slight postponement of the departure from Johannesburg. Before leaving these two analyses, it may be remarked that the Bristol 175 almost exactly fits this optimum speed category, even though the original requirement was obtained from totally different considerations.

Some of the other problems are geographical. For example, looking a long way into the future, it may be possible to consider non-stop operation ignoring international boundaries and without following any prescribed corridors. For example, consider a Map of the World centred about Prague (Fig. 3). A range of 6,250 miles—that is, a quarter of the way round the World—covers all the important capitals of the world except Buenos Aires, Sydney and Wellington, so that this distance might seem to be almost

Fig. 4. Map of the World centred about Alice Springs.

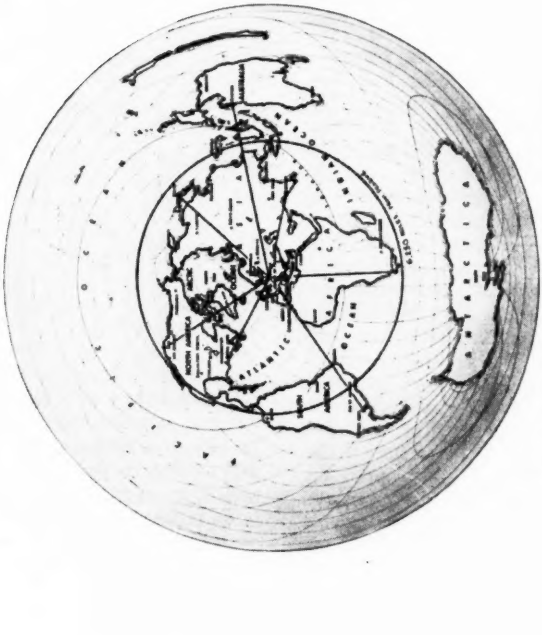

Fig. 3. Map of the World centred about Prague.

TABLE I

TRENDS IN CRUISING SPEED AND ALTITUDE

Aircraft	*Condition*	*Speed*		*Altitude*
		Indicated	*True*	
Dakota	Max. Cruise	189 m.p.h.	220 m.p.h.	10,000 ft.
Constellation 749	„ „	231 m.p.h.	315 m.p.h.	20,000 ft.
Stratocruiser	„ „	218 m.p.h.	325 m.p.h.	25,000 ft.
Bristol 175	Constant C_L	206 m.p.h.	348 m.p.h.	30,000 ft.
Comet	„	254 m.p.h.	475 m.p.h.	36,000 ft.
	Increase	35%	116%	26.000 ft.

NOTE.—The speeds are given at mean weight and (I.C.A.N. + 15°C.) temperature

the ultimate range ever required by an operator.

A view of the world centred about Australia is not so familiar to English readers. Fig. 4 is a Map of the World centred about Alice Springs. In this case, the same range of 6,250 miles reaches only one other continent, Asia; Europe, Africa and both North and South America are far beyond. From the point of view of an Australian airline therefore 6,250 miles range would be nothing like enough for direct non-stop operation.

As a general rule, the higher speeds of future aircraft are obtained by flying higher, and Table I has been prepared to illustrate this point. In the past 10 years, the cruising speed of transport aircraft has more than doubled, from the Dakota at 220 miles an hour to the Comet at 475 miles an hour. A great deal of this is due to the increase in cruising altitude from 10,000 ft. to 36,000 ft., for the indicated cruising speed has gone up only 35 per cent.

There is probably a limit set to the cruising speed of future transport aircraft by the practical operating height*. For example, it already appears that there is a critical height above which it is necessary to make an immediate dive if there is any failure of the pressurisation system. It is doubtful if any operator will consider operating above about 40,000 ft. until he has gained considerable experience of the reliability of such systems.

While these high altitudes lead to higher speeds, they are absolutely essential for economy, for it is only at these heights that the specific range of turbine aircraft even approaches that of present piston-engined aircraft. Most of the flight therefore will be above cloud height, and it has often been suggested that for this reason cabin windows will become less and less an attraction. B.O.A.C.'s own experience is just the reverse, as shown by a report written after a first flight in the Comet:—

> "The cabin windows are of generous size, and attractive shape. I found myself grateful for them at 35,000 ft. The sky, clouds and colours will provide fresh interest at such altitudes for those who appreciate this kind of thing. There will, too, be views of continental dimensions on favourable occasions and I expect passengers will not quickly forget what it is to be able to enjoy the unusual experience. I believe that in including these windows we have correctly anticipated the need to exploit this inherent advantage of high altitude flight."

The second advantage hoped for from turbine engines in transport aircraft is reduced vibration and a general improvement in passenger comfort. In the same report it is said:—

> "The outstanding sensation seemed to me to be one of smoothness of flight compared with current piston-propeller experience. The whole aeroplane looked and felt quite still. There was none of the customary quivering or rattling; touching a window, for instance, produced the same sensation as at rest on the ground; I imagine that one's handwriting would have been quite unaffected. The impression of smoothness was just as noticeable during taxying and take-off, and the aircraft appeared to glide along. I believe this feature will prove to be a great step forward in reducing fatigue of crew and passengers, and in making air travel more pleasurable. Perhaps some of us have become accustomed to accept as inevitable the harsh battering vibration of our present-day aircraft, and have somewhat

*Irrespective of any Mach number limitations, which are independent of height above the tropopause.

wrongly tended to concentrate our criticisms upon noise itself as the principal source of discomfort."

3. OPERATIONAL PROBLEMS

Operating problems seem to fall into three groups:—

(*i*) problems which exist in present operations, but which look like being solved with current knowledge.
(*ii*) some old problems, for which new solutions are required.
(*iii*) entirely new problems.

3.1. CURRENT PROBLEMS FOR WHICH SOLUTIONS ARE AVAILABLE

These are the old problems which only require an extension of present design and operating techniques. A good example is pressurisation.

Figure 5 shows a typical flight plan of a turbine transport. The characteristic points are a continuous climb throughout the cruising phase, a rapid climb to reach economical altitudes as soon as possible, and a very speedy descent. Incidentally, these angles of climb and descent are larger than those to which passengers have been subjected previously. For the Comet, angles of climb and descent are 4° and 3° respectively; for the Bristol 175, 5° and 2°. Allowing for the angle of attack, this explains why it seems difficult to walk up the gangway of the Viscount during climb. This diagram also shows the limits imposed by the pressure differential. For example, at a maximum cabin altitude of 8,000 ft., the descent to a sea level airport must extend over at least 36 minutes if the rate of increase of cabin pressure is not to exceed that corresponding to 200 ft./min. A high differential pressure has several advantages. On the Bristol 175, B.O.A.C. required the cabin altitude to be kept below 5,000 ft. for medical reasons, but this has an operational advantage for, provided that the descent takes longer than 24 minutes, there are no other restrictions on the rate of descent of the aircraft. On a turbine-engined aircraft, a high design differential pressure is particularly important to provide a margin of "stretch."

To cope with this complicated flight plan there must be completely automatic pressurisation controls, especially if the Flight Engineer is dispensed with as a regular member of the crew, which must be done in order to exploit the simplicity of gas turbines to the full. It pays to reduce the number of crew as much as possible. Not only do extra crew members cut into payload, but their salaries are a substantial item in the direct operating cost. This is especially the case abroad, because of subsistence, particularly on long routes where there are "slip" crews. Worse still, extra crew members cut into the space available for passengers. A good example of this is the Canadair Four, where there are four operating crew, and the cockpit is only 8 ft.

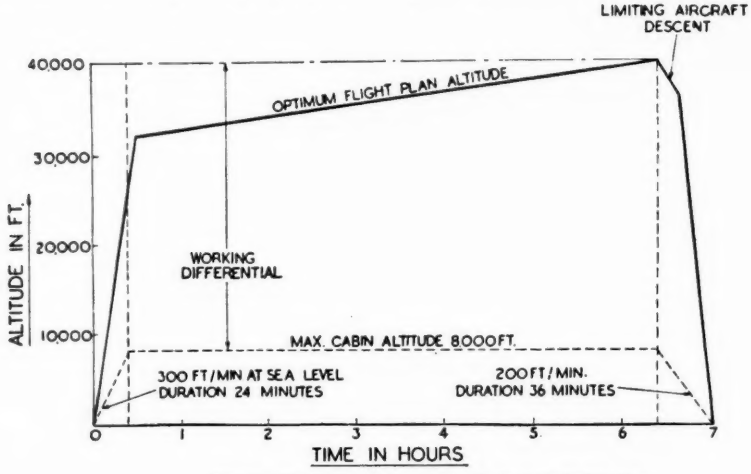

Fig. 5. Typical turbine-engined aircraft flight plan.

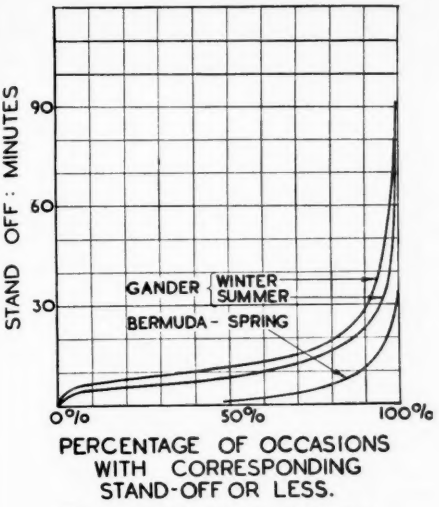

Fig. 6. Analysis of stand-off times at Gander and Bermuda.

long from the dashboard to the back end. The Hermes IV has an operating crew of five and the cockpit is over 10 ft. long. This means that with a little adjustment at the back end, one extra row of four passenger seats could have been fitted in the same fuselage.

For years, American domestic airlines have been able to do without separate radio operators. The reasons are not hard to find. To begin with, there is no language difficulty, but the main reason is the excellent ground facilities. The U.S. domestic airways are littered with four-course ranges and are now being covered with V.H.F. omni-range beacons. Wherever these facilities have been provided abroad, airlines have been able to dispense with separate radio operators. Pan American Airways have done so for years between Miami and Rio de Janeiro, have just started to do so between England and Damascus, and are planning to do so throughout Africa and Asia.*

Much more is now known about the ground procedures necessary with turbine transports. On the Comet, the cockpit check takes five minutes before starting the engines, which it is possible to do in an average of one minute. There is no warming up and the remaining aircraft functions are checked during the five minutes taxying out. There is no final check at the end of the runway, but if there seems to be full thrust when all engines are opened up, the brakes are released and off she goes. This is much simpler than with, say, a Constellation or Stratocruiser.

The last item in this first group of operating problems is the overhaul of turbines. Bench-testing involves staggering quantities of fuel, and the cost and size of ground test plants is greater than for piston engines. It is likely that it will become increasingly the practice to sub-contract all overhaul to engine manufacturers or to firms specialising in this work.

3.2. Current Problems Requiring New Solutions

The first of this group of problems is air traffic control. As far as is known, turbine aircraft do not introduce any particularly new problems in this field. What they do is to render imperative the revision that is already overdue. For one thing, the present method of establishing cruising heights in relation to compass heading will be unworkable with the steady climb throughout the cruise that is desirable.

Almost everyone who has landed at a major airport has been "stacked" at one time or another. "Stacking" or "stand off" are terms given to the procedure whereby aircraft awaiting their turn to land under conditions of bad visibility or high traffic density are instructed to circle specified points at various heights. Fig. 6 shows that stand-offs of half an hour are by no means the exception, even at an airport with almost no local traffic, such as Gander, and over 90 minutes has been experienced. With piston engines, a low average height during the stand-off period is an advantage, because the indicated air speed for minimum power does not vary with height so that the power required and the consumption are lowest at sea level. With gas turbines, however, the stand-off consumption is greatest near sea level. Until such time as fully automatic block control is introduced throughout all flights to congested airports, it has been suggested that turbine-engined aircraft should circuit at about 20,000 ft. until given clearance to land. The distance covered in the descent would be sufficiently great to enable the aircraft to enter the traffic control pattern low down and thus to land without further delay.

* Since extended very considerably.

Re-circuiting might not be permissible, and any missed approaches may have to be followed by an immediate diversion to an alternate. This is one important lesson of the Berlin Airlift, which was such an outstanding operational achievement. This diversion to alternate will clearly have to be done on the optimum diversionary flight plan, which again introduces complications in air traffic control as the aircraft will be in a continuous state of climb or descent.

The problems of ground traffic control are equally numerous. First of all, there is the fuel consumption during taxying. On the Comet, it is about 35 gallons per mile, which is enough to break the heart of any keen motorist! This figure can be reduced if the fewest number of engines required to maintain the essential services are used during taxying, and particularly during holding at the end of the runway before take-off. Tests have already shown that on this aircraft three engines can be shut down and started again without an external battery cart, using only the aircraft batteries and the generator on the fourth engine.

At one time a lot of trouble was expected from the slipstream, but this may have been exaggerated a little. The jet pipes on the Comet are approximately horizontal and 6 ft. off the ground, so that the jet blows over the head of the average man, although it still interferes with aircraft standing in line at the end of runways. The temperature may reach 100°C., and there have been cases of the runways being badly seared by aircraft with jet pipes inclined downwards. Airport engineers are alarmed at the stresses which occur in concrete under these conditions, although so far no case has been reported of one slab of concrete jumping on top of another.

Some of the navigational difficulties expected, all of which are due to the higher speed and the shorter time available to make calculations, are now explained briefly. Present methods of navigation essentially tell the navigator where he was when he started taking observations. By the time he has worked it out and plotted it, he is somewhere else and he has to make a considerable correction before he can begin to calculate what alteration of course, if any, he ought to take to arrive at his destination. At high speeds this correction increases correspondingly. It is no use hoping that because the speed is so high the angle of drift is reduced, because the average wind speeds increase with height up to the tropopause and, in fact, the angle of drift tends to remain constant everywhere in the troposphere for a uniform wind pattern.

Two specific types of navigational error are magnified at high speeds. First of all, the pitot head pressure increases by a factor of $[1+\frac{1}{4}(\text{Mach number})^2]$ so that at a Mach number of 0.5 there is already an error of 6 per cent. and at a Mach number of 0.8 an error of 16 per cent. It is impossible to compensate the air speed indicator exactly for this error because the Mach number varies with the temperature, and there are also difficulties in determining the outside air temperature at these speeds. If a bulb in the air stream measures the temperature, the impact of the air on the bulb raises the temperature by an amount which is proportional to the square of the indicated speed, but which has to be found by test for each individual aircraft. Secondly, the errors due to compass acceleration and Northerly turning error are also increased at high speeds; however, the higher inherent accuracy of modern gyrosyn compasses may prevent this being a problem.

It is generally believed that astro-navigation will find less and less place on future aircraft, at any rate on medium ranges. To begin with, it is much too slow, and then the error of an astro-fix goes up approximately as the square of the speed and there are a number of worrying corrections that have to be made.

More or less the same arguments can be advanced against Loran, Gee and Consol, each of which takes some time to provide a fix, and requires a large chart table on which to spread the special hyperbolic maps. It does not apply to the Decca navigator to quite the same extent as this normally gives an instantaneous fix, although it does not provide an immediate instruction to the pilot.

It seems a most important point that the most useful types of navigational aids, particularly on high speed aircraft, are those which inform the pilot directly what action he has to take to get to his destination. The pilot should also be afforded sufficient information to permit him, or another crew member, to determine roughly where he is if he needs to know. In other words, track and distance predictors. This is the principle of homing on a station using a radio

compass, and there is a tendency to lose sight of the merits of this principle. Digressing for a moment, it is the same as that used in the Sperry Zero Reader which shows a pilot which way to move his controls to follow, say, the I.L.S. glide path and localiser beams, although not the displacement from these beams, which is the indication given by the I.L.S. cross-pointer-indicator, which at first sight looks very similar. The startling results obtained by the use of the Zero Reader will make possible considerable reductions in operating minima. They also show clearly that the principle of co-ordinating instrument readings is sound. In the next few years there is likely to be a considerable increase in the number of instruments of this sort, with a significant effect on instrument layout.

Reverting to the problems of navigation on high-speed aircraft, the combination of distance-measuring equipment and suitable ranges seems to be almost ideal; this provides an immediate indication of distance and bearing from any one of these stations, thus fixing position without ambiguity. American thought is tending towards distance-measuring equipment shown on a meter, and a fantastic accuracy is expected as the means for establishing position exactly, and with the hope of calculating an absolutely reliable E.T.A. from a long distance away. In the United Kingdom it is felt that there is much to be said for combining distance-measuring with the visual indication of search radar, which gives a useful method of avoiding ground collision at the same time. Airborne search radar can also be of great assistance in avoiding the severe turbulence and precipitation associated with cumulus and cumulo-nimbus clouds. Both are important for high-speed aircraft. Because of the characteristics of turbine-engined aircraft, particularly turbo-jets, the optimum climbing speeds are higher than for piston-engined aircraft and, because such aircraft are usually aerodynamically clean, the forward speed in descent may also be fairly high. For both reasons the effect of turbulence is magnified, so search radar must be used to avoid it as far as possible. Search radar also helps to prevent damage from hail. Already the problem of denting the leading edges and the nose is quite serious on some aircraft, particularly with thin gauges of material.

3.3. New Problems

An important characteristic of turbine-engined aircraft is the higher temperature sensitivity, that is, the larger variation in performance caused by any change in ambient air temperature. This obviously affects the scheduling of aircraft in several ways. First of all, it so limits the aircraft performance on hot days that the take-off weight will often have to be drastically reduced. Coupled with the reduction in specific range, to be mentioned later, this would often prevent a particular sector from being operated at all, even with no payload. This means that it may be necessary to find some means of scheduling the aircraft out of critical airports in the cooler times of the day. In practice it is not always possible or wise to do so on a long route, because a delay may involve wanting to take-off just when this is impossible, thus involving further delay. The most promising approach seems to be to make long-term plans on the basis of take-off with the payload corresponding to an average load factor of, say, 70 per cent., with a small wind component down the runway. If there are more passengers on any particular occasion, or if the expected wind component does not exist, then a delay has to be accepted.

Another problem introduced by the higher temperature sensitivity is the difficulty of anti-icing of turbines. Heating the incoming air seems out of the question. Apart from the colossal power required, the effect is the same as continuous operation with tropical air temperatures, resulting in a substantial loss of range.

The effect of high intake air temperatures on take-off power has been appreciated for a long time, but the effect on range is not so well known. This is really a consequence of the types of cruise control which are necessary. With all types of engine an increase in air temperature results in a loss in power, and also an increase in specific consumption. On turbine-engined aircraft, however, this loss in power causes an additional loss of altitude and hence a further reduction in specific range. Actual figures are given in Ref. 3.

The range of temperatures is shown on Fig. 7, on which are drawn also some of the "standard atmospheres." The British Civil Airworthiness Requirements' "Temperate Maximum" can be exceeded, particularly at low altitude, although the

" Tropical Maximum " really is the absolute maximum. From a certain height upwards, the temperature does not continue to fall, but remains constant or even increases slightly. This critical height is that of the tropopause, at the bottom of the stratosphere. In actual fact, this height is not constant, nor is the stabilised temperature. The average height is about 32,000 ft. in temperate zones, falling to 22,000 ft. at the Poles, but rising to as much as 60,000 ft. in the tropics. This height varies considerably from day to day, although differences of $\pm$4,500 ft. are only exceeded on about one day in eight, the lowest heights being usually associated with bad weather.

Figure 8 shows how the average wind speed varies with height. The tropopause is highest in the tropics and this is coupled to another important fact. Since the temperature lapse rate in the tropics is usually greater than that at the Poles, the net result is that the temperature in the stratosphere at the tropics falls below that at the Poles. In fact, in winter the warmest stratosphere appears to be that in the latitude of Europe. However, Fig. 8 shows that the highest winds are also those in latitude of 50°N., so that the combination of the highest wind and highest temperature during the worst season is likely to be a serious limitation in one direction on the North Atlantic.

As a matter of interest, at these latitudes, the normal (*i.e.* the vector mean) wind blows due easterly or due westerly, there being a few areas of easterly winds near the equator and in the Antarctic. It is, therefore, somewhat fortunate that on the majority of present routes the sector tracks cut the high altitude normal vectors at considerable angles, so that their full force is not felt, except in those areas where the sectors can be broken down conveniently. In particular, routes from Europe to South Africa appear to offer the easiest conditions of all, as the normal wind is abeam, although there may be a considerable departure on any particular flight.

Recently, much has been heard about the phenomenon of jet streams, that is, belts of very high wind speed, sometimes only about 30 miles wide and a few thousand feet deep, but usually several hundred miles in length, although not in a straight line. The speeds are extremely high and 232 m.p.h. has been recorded over England. Obviously, these jet streams can blow even the fastest aircraft a long way off its track in a very short time—another reason why really fast navigation methods are necessary.

Another problem is that of clear air turbulence which has been under investigation by British European Airways for two years. This is turbulence which occurs in absolutely clear air and is believed to be due to a high rate of shear between successive air masses. It is very different from that of cloud turbulence which produces a

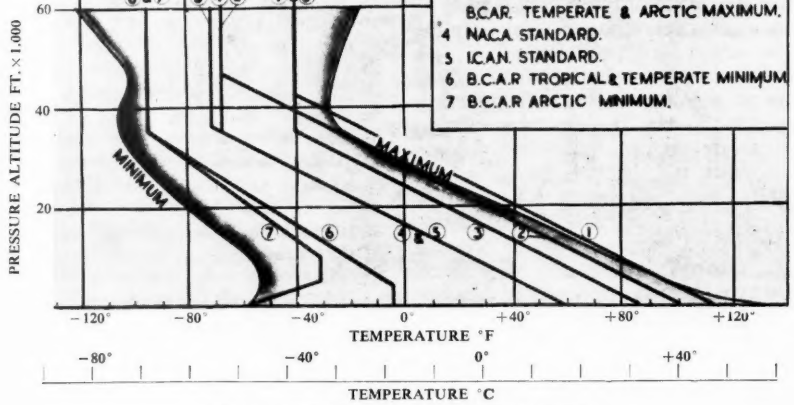

Fig. 7. Variation of temperature with height.

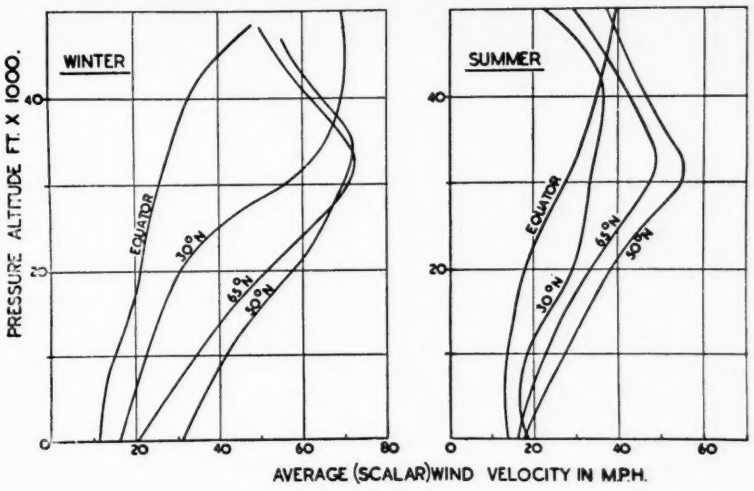

Fig. 8. Variation of headwind speed with height and latitude.

characteristic wallowing. Clear air turbulence is like driving a car over a series of bad potholes. There is some chance that the most severe bumps are associated with jet streams, and the experience of the Comet, which encountered a succession of bumps ending with two at $+3g$ and $-1.6g$, is an example. B.E.A. records show that the areas of such turbulence are 30-100 miles in size; B.O.A.C. records give rather larger areas up to 150 miles. B.O.A.C. has recorded cases over the North Atlantic, down to Bermuda, and in the Middle East and Persian Gulf.

It may be noticed that almost all of the new problems described are likely to involve the establishment of new or improved ground facilities for their solution. This is characteristic, for there is no hope of operating these new types of aircraft efficiently otherwise. Unfortunately this costs money and funds are difficult to come by in these days. The three factors which seem to be the most important are:—

(*i*) Improvement in communications, both point-to-point on the ground and also ground-to-air, so that changes in weather and so on can be notified immediately, their effect assessed, and resulting instructions passed to the aircraft in flight with the least possible delay. This improvement is absolutely necessary for operational reasons, let alone traffic control, for without it there can be no great reduction in the weight of fuel reserves.

(*ii*) The second point is better meteorological facilities. From what has already been said, it is obvious how important it is to set up a world-wide forecast service for both high altitude winds and temperatures. To give an idea of how serious this is, it is likely that if a flight plan for a flight at 30,000 ft. is made on records which are 6 hours old, the probable error in the wind velocity is over 25 m.p.h. In the list of better meteorological services, adequate fore warning of jet streams and areas of clear air turbulence should also be included.

(*iii*) Last, it seems likely that a chain of transponder beacons will be necessary down every traffic route, that is, small self-contained radar beacons that reply on another frequency when interrogated by a signal from an aircraft. Used with search radar, these will give distance and heading information directly. With such beacons, navigation will be simple and reliable.

Some time has deliberately been spent on this third set of operating problems, partly because they represent the unknown and partly in order to stress the magnitude of the task ahead of the operators.

4. AIMS AND PRINCIPLES FOR MANUFACTURERS AND OPERATORS

4.1. Reduction of Operating Costs

It is now possible to make reasonably reliable estimates of the operating cost of turbine aircraft. It is clear that on an operating hour basis the cost of operation is unlikely to show any reduction, if at all. On the other hand, the cost per capacity-ton-mile, which is the figure eventually determining the fare paid by the passenger, is likely to show a considerable decrease due to the greater rate of work brought about by the higher cruising speed, *i.e.* the increase in ton-miles per hour. The extent of this reduction, however, will depend upon three conditions:—

(*i*) The degree of reduction in fuel reserves which is made possible by improved methods of operational control.

(*ii*) The reduction in fuel consumption. Turbine-engined aircraft use so much more fuel per mile than present aircraft that the cost of fuel becomes the largest single item. On the Comet, it will amount to no less than 45 per cent. of the total direct operating cost, although the corresponding figure on the Bristol 175 will be lower. The relatively large proportion of the cost that is due to the fuel is one reason why devaluation has hit soft currency operators so badly, for both high octane fuel and aviation kerosine are dollar supplies.

(*iii*) A higher utilisation to offset the higher initial costs of new fleets.

A great expansion in air transport seems imminent, even if the rate of this expansion is less than that optimistically planned at the end of the Second World War. The numbers of aircraft which will be required are much smaller than commonly supposed, and aircraft fleets of over 150 will probably be unusual even among major operators. For these reasons, civil transport aircraft manufacture will always be set apart from large scale production. In spite of this handicap, the delicate balance between operating profit and loss must be maintained if the Aircraft Industry is to make even a small living from civil contracts.

Reference is now made to those principles which should be borne in mind throughout detail design, that is, after the framework of the basic design has been settled.

4.2. Detail Design Requirements of an Operator

The first essential is *ease of maintenance*, covering accessibility, ease of ground checking, means of simple adjustment and the ability to make these adjustments as far as possible on the bench before fitting the particular item to the aircraft.

The second point is *reliability* and an increase in the life of each component: about 50 per cent. of present delays are due to engines and their accessories.

The third point is *consistency* of operation. For reason of scheduling, it is necessary to base performance on the worst aircraft of a fleet both from the point of view of weight and fuel consumption. It is important that the worst aircraft be just as good as the best, for this reason.

The fourth point along which development is required is in the direction of greater *predictability* of operation. This is quite different from consistency. It is clearly of no use if engine design is such that, although a certain type of engine is cleared to operate 1,000 hours between overhauls, a number of unscheduled engine changes occur at 200 hours, for the cost of an unscheduled engine change is out of all proportion to other costs. This also applies particularly to instruments. Records for present gyro horizons and directional gyros show a less than even chance of a particular instrument achieving its agreed "overhaul" life.

Finally, the last great aim is *standardisation*. One means of decreasing cost is by the use of parts which will, as far as possible, be common to other aircraft. For present airline aircraft, the cost of spares is as much as 25 per cent. of the cost of the whole fleet. Put another way, it means that there is a potential saving of one-fifth in the total outlay. Put in yet another way, it means that the operator could afford to purchase about one more aircraft in ten if standardisation were an accomplished fact.

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REVIEWS

The following are reviewed:—

Advanced Strength of Materials
The Behaviour of Engineering Metals
Parachutes
Jane's All the World's Aircraft 1951/52
Adhesion and Adhesives
Airplane Aerodynamics
Classical Mechanics
Marshal Without Glory
Handbook of Agricultural Pest Control
Flight Without Formulae (*Second Edition*)
Coral Circus (*Fiction*)

ADVANCED STRENGTH OF MATERIALS. D. A. R. Clark. Blackie & Son Ltd., London and Glasgow 1951. 329 pp. Illustrated. Index. 35s. net.

When one meets a new text book in a field which is already well covered with standard works, it is natural to ask whether the author has anything new to say, or whether he covers old ground more satisfactorily than his predecessors. It is to be regretted that in the case under review the answer must be in the negative.

The work is intended as a continuation of the author's "Materials and Structures" to the standard of Part II Engineering Degree. The syllabus is covered in the usual way, with plenty of worked examples and a generous selection of questions at the end of each chapter. It is a definite limitation, however, that continuous reference is made to the earlier work. In spite of this, in several places there occur seemingly unnecessary repetitions of sections from that book.

This is but one symptom of a curious lack of consistency which appears throughout. Thus, worked examples appear in great algebraic detail, while textual explanation is sparse. This lack of explanation is a fault of the whole book, and is paralleled by an extreme brevity of definition which often amounts to serious ambiguity. Examples which may be quoted are the lack of a physical explanation of the whirling of shafts, the lack of a defined sign convention for the fixing moments of continuous beams and the serious confusion of notation in the beginning of the chapter on flat plates.

Among errors which may be noted are the ignoring by the author of his own definition of stress in "Materials and Structures," the remark on the direction of torsional shear stresses on p. 131, and the notation of $\int_0^A da$ for an area integral which conjures up in the reviewer's mind visions of an area appearing from nothing like a genie from a magic lamp!

The publishers may be heartily congratulated on a production of high quality: paper, printing and binding are excellent. The Table of Contents and Index, however, are by no means as comprehensive as in the previous book, a retrograde step from the point of view of students. The diagrams are of very high quality, although the book's inconsistency shows itself once more in that a few of them are inaccurately drawn or misleading. The quality of production is reflected in a price which, when taken together with the cost of the earlier and complementary book, compares unfavourably with those of its competitors.

While the book is adequate for continuation purposes for those who have used "Materials and Structures," it cannot be regarded as worthy of serious consideration as an alternative to existing standard texts.

THE BEHAVIOUR OF ENGINEERING METALS. H. W. Gillett. John Wiley & Sons, New York. Chapman & Hall Ltd. London 1951. 395 pp. Illustrated. Index. 52s. net.

For much more than a generation the publication of an article, paper or book by Dr. H. W. Gillett has been something of an event. One well knew that in reading the work in question, one would add to one's knowledge and would at the same time feel grateful for the directness and lucidity with which this knowledge was presented.

To-day, when the latest book of this Grand Old Man of American Metallurgy comes to hand, one has the same thoughts, but with an added force, for alas! its author is no longer with us—he has passed into the Shades, but he has left much which will long endure.

Gillett was not of the metallurgical school which, on the strength of an arbitary conception of the spacing of atoms and aided by clever mathematics, produces wholly unbelievable answers to its self-imposed questions. He had little of this art but, by virtue of his knowledge derived from observation and experiment, he knew what metals were rather than what, from a doubtful mathematical-physical concept, they should be.

His last work, published posthumously, might well be called " Metallurgy for Engineers," were it not for the fact that this title has been previously used. It contains nearly four hundred pages, twenty-four chapters, a useful appendix and an author and subject index. It covers a very wide field in an entirely satisfactory manner.

Gillett writes with profound knowledge of the behaviour of metals and alloys. This he acquired as a result of a lifetime of laboratory and practical experience. What the microscope, innumerable results observed from the whole galaxy of testing machines and instruments, methods of manufacture and performance of countless mechanisms and structures used in many engineering fields had taught him, he sets forth with lucidity and understanding. His shrewd comments, often in aptly chosen terms of homely analogy, are almost always illuminating, for he truly knew his metallurgy and was deeply conscious of the practical problems of the metal user.

This last book should be read by engineers, whether aeronautical or not, and it would also be advantageous to metallurgists to read it, for it will provide them with material, indeed very powerful material, for teaching the almost metallurgically unteachable. As one of the same generation as Gillett, the reviewer pours out his libation of praise—a worthy, wise and lovable man has left us, but thanks be, he has bequeathed us a modicum of his great learning.

PARACHUTES. W. D. Brown. Sir Isaac Pitman & Sons Ltd. London 1951. 322 pp. 110 Illustrations. 40s. net.

Mr. Brown has performed a useful service in gathering together in one volume much information on the design, development, and operation of parachutes. This book, containing twenty-five chapters, covers a wide field ranging from very full descriptions of particular items of equipment to the mathematical analysis of parachute stability and opening forces. The various uses to which parachutes can be put, air crew safety, paratrooping, equipment dropping, and so on, are also covered.

The author has been consistent in that the descriptive matter is given with a wealth of detail which will be of considerable interest to those concerned with the design and operation of parachutes; a minor comment here is that the addition of simple sketches, to supplement the photographs of equipment, would assist the reader in following the narrative. When it comes to the characteristics, mechanics, and general behaviour of parachutes however, an even treatment is not found and it is a little difficult at times to understand what standard the author is attempting to achieve. To quote one passage, " Thus because both the bulk and the weight of a parachute increase approximately as the square of the diameter, doubling the diameter would probably increase the bulk and the weight to four times their former value." Does the reader really want to be informed that the square of two is four? Repetitions are frequent. This is permissible if the purpose is to underline some important point or relationship which must be borne in mind for the proper understanding of the text, but it is apt to be irritating when the matter is of little significance. On the other hand some subjects have received scant treatment, as for example the measurement of shock and development loads on parachutes when they open; no results of such tests are given although these have now been established with a considerable degree of success by experimenters in this field and add greatly to our knowledge of parachute opening forces.

The book is well printed and the mathematical work set out clearly. It is felt, however, that the general arrangement of the contents would have been improved if steps had been taken to separate more definitely the historic, the obsolescent, modern design and techniques, and mathematical analysis. Some of the empirical formulae, particularly those denoting fabric strength, are somewhat confusing in the absence of any relevant discussion or explanation. Also it is hoped that, in future editions, the author will clarify such passages as the following, " Generally, with tail-less aircraft, an anti-spin parachute installation is fitted at each wing tip. In certain circumstances, for instance, when the wing tips are very thin, a single parachute may be used in the tail."

The inclusion of a Glossary of Parachute Terms in addition to the Index is a happy thought, since some of the phrases, although familiar to students of the subject, may be novel to many readers. An unfortunate omission, however, is the absence of any detailed reference to original papers and publications, particularly those which have a bearing on the more mathematical material in the book.

JANE'S ALL THE WORLD'S AIRCRAFT, 1951/52. Edited by L. Bridgman. Sampson Low Marston & Co., London, 1951. 293 pp. Illustrated. Index. £4 4s. 0d. net.

No doubt the approaching era of guided missiles, leading—who knows?—to satellite vehicles and space travel, will serve to enlarge still further Jane's all-embracing orbit, but for the time being, these familiar pages still show little sign of such things to come. Apart from a few rocket and ram-jet motors in the Engine Section and guarded references to work on guided missles by one or two American aircraft manufacturers, there is nothing to suggest such a change in scene. As far as contemporary aircraft development is concerned, there is plenty of material from which to take stock of the present situation.

For it is this taking stock of what is happening all over the world that makes the appearance of " All the World's Aircraft " each year a notable event in the aviation calendar. Primarily a book of reference to which one turns for quick information for the rest of the year, each issue of Jane's when first published serves for a moment the quite different purpose of providing a broad review of world-wide progress. In its way, it is a sort of S.B.A.C. Show for all the aircraft-producing nations.

This year some of the lessons are clearly defined, others may only be more dimly seen. But in either case, they are obviously important. In Britain, production orders for our first four-jet bombers, swept-wing fighters and turbine anti-submarine aircraft are obviously landmarks as significant in the military sphere as the more advanced production activity on the Comet and Viscount is to commercial aviation. In research, the British emphasis on the delta-wing configuration can be clearly seen, as can the continued accent on low wing loadings for turbine-powered high-flying aircraft and the gradual, but belated swing to advanced high-lift devices for conventional layouts. The British helicopter situation remains disappointingly static. In a less important field, the production at long last in Great Britain of a high performance sailplane, competitive with any type in production abroad, should not pass unnoticed.

The United States continues to maintain her massive lead in commercial aviation and in research although British turbine transports, if they can be built in sufficient numbers, may help us to challenge the former. Developments in fighter aircraft design in the Soviet Union and, more recently, in this country, suggest that the remarkable ascendency established some years ago by the Sabre is not being maintained. However, the cult of high wing loadings and elaborate flaps is obviously still paramount in America and the continuous energetic " stretching " of every successful aircraft to higher weights and larger capacities continues unabated with very obvious benefits to their manufacturers and operators.

The Russian picture is inevitably vague although the Korean War has helped to show something of the remarkable technical advances made by the Soviet since the Second World War. Jane's shows disappointingly little of this. The difficulty of getting any information on Russian aircraft is well known. Even so, as much as possible of the immense amount of unofficial—and no doubt largely spurious—data on Russian aviation that has appeared in America and elsewhere in the past year should be sifted, analysed and commented upon. Study of the Russian Section of Jane's 1951/52 leaves the impression that this task has not been as well done as its importance deserves.

Other criticisms are small, although many users will no doubt continue to feel that the presentation of aircraft data should be in more standardised and comprehensive form. No doubt the sheer volume of work involved prevents attainment of such an ideal without greatly increased costs of production. Presumably cost and lack of space also account for the continued absence of illustrations from the Civil and Military Aviation Sections although their inclusion up to 1945/46 was generally appreciated. The First Flights Section, started last year, is an interesting and useful record which deserves to be expanded and kept as complete as possible.

All in all, Jane's maintains its high standard. May it long continue to do so.

ADHESION AND ADHESIVES. N. A. de Bruyne and R. Houwink. Elsevier Publishing Co. Ltd. Amsterdam. Cleaver-Hume Press, London 1951. 516 pp. 205 figures. Index. Bibliography. 70s. net.

The advent of this new book on adhesives by two such well-known authorities in this field must be very welcome to technologists in almost every type of industry. From a purely technological point of view, the need for a comprehensive statement and systematisation of the vast range of adhesives in use and in the development stage has for long been felt. The present volume presents such a systematisation in an admirable way. There can be no criticism of the book on this score. Every conceivable type of problem where adhesion is involved is described in detail by someone actively engaged on the problem.

The critic has cast about him to find some small omission in the list of applications dealt with and the only one he has succeeded in finding is that involved in sand-core moulding.

The book is not however in any sense a manual and the theoretical, physical and chemical principles are described in all cases where fundamental work has been done on the subject.

As a test for the completeness of the theoretical section, the reviewer examined in some detail the section dealing with the chemistry of the phenol-formaldehyde adhesives and was most agreeably surprised to find a complete survey of modern views concerning the presence of ether links in these structures.

The book brings home to one very clearly the vast amount of work which remains to be done before it will be possible to tailor organic adhesives to a particular job, but the survey of our present knowledge on this score is a most valuable feature.

It is perhaps worth pointing out that the book includes cements and solders in its context.

AIRPLANE AERODYNAMICS. D. O. Dommasch, S. S. Sherby and T. F. Connolly. Pitman Publishing Corporation, New York 1951. 520 pp. 40s. net.

This is one of the many text books which began as a series of lectures, in this case written for test pilots of the United States Navy. The authors' approach to aerodynamics is not really, as the dust cover claims, " a mathematical one " but it is essentially a practical approach. The physical nature of the phenomenon is first explained and any formulæ useful in numerical calculations are developed. There are many " illustrative examples " in the text in which the use of the formulæ is demonstrated and each chapter ends with a series of numerical problems (with answers) and references for further reading.

The breadth of the subject matter is indicated by the fact that six chapters on basic aerodynamics are followed by one on The Propeller, one on Aircraft Propulsion, two on Performance Problems, five on Stability and Control and one on Seaplanes. The latter is very welcome since so few text books spare space for the problems of the flying boat and seaplane. Chapter 8 on Propulsion seems unnecessarily detailed for a book on aerodynamics. As an introduction to Performance Problems some data is needed on the performance of various types of engine, but discussions on Otto Cycles and aftercoolers are surely not necessary.

A text book on aerodynamics is now expected to regard every aeroplane as having swept wings and to be moving at Mach numbers where compressibility effects are appreciable. Data given for unswept wings at low speed should be followed by some indication of the effect of sweep and of compressibility on the data. For example, the empirical formula on p. 380 for the downwash at the tailplane is not true for an aircraft with swept wings. A surprising omission in the very detailed section on take-off and landing performance calculations is of any reference to ground effect on drag.

The British reader is at a disadvantage in the stability and control chapters since the notation used differs considerably from our customary notation. We recognise q as shorthand for $\frac{1}{2}\rho V^2$ but instead of our b_1/b_2 the Americans write in full

$$\frac{\partial C_{he}}{\partial \alpha_t} \Big/ \frac{\partial C_{he}}{\partial \delta_e}$$

with the result that some longitudinal stability equations look very cumbersome. More serious is the use of symbols in common use in the United Kingdom to mean something slightly different. For example, we define n_v as $\partial C_n/\partial\beta$ and $\frac{n_v}{i_v} = \left(\frac{b/2}{k_z}\right)^2 \frac{\partial C_n}{\partial \beta}$.

This latter quantity is defined in the book (p. 443) as $n_v/2$, so that confusion is inevitable.

It is also inevitable that a book covering so much ground shall be found superficial in parts, yet the total effect is to present a clear picture of the aerodynamics of the modern aeroplane. The clarity is enhanced by the high quality of the paper and the excellent printing of the text, equations and figures.

CLASSICAL MECHANICS. Herbert Goldstein. Addison-Wesley Press, 1951. 399 pp. Illustrated. Index. 50s.

The author of this book is a member of Harvard University and is not to be confused with Professor S. Goldstein, who is so well known in the aeronautical world. As the author states in his Preface: " An advanced course in classical mechanics has long been a time-honoured part of the graduate physics curriculum. The present-day function of such a

course, however, might well be questioned. It introduces no new physical concepts to the graduate student. It does not lead him directly into current physics research. Nor does it aid him, to any appreciable extent, in solving the practical mechanics problems he encounters in the laboratory. Despite this arraignment, classical mechanics remains an indispensable part of the physicist's education. It has a twofold role in preparing the student for the study of modern physics. First, classical mechanics, in one or another of its advanced formulations, serves as the springboard for the various branches of modern physics. . . . Secondly, classical mechanics affords the student an opportunity to master many of the mathematical techniques necessary for quantum mechanics while still working in terms of the familiar concepts of classical physics." These observations are very just and they give the key to the aim and tone of the whole book, which is written by a mathematical physicist for mathematical physicists.

In view of what has already been said it will be clear that this is not a book which aeronautical engineers will wish to consult in their professional capacity. However, given the necessary mathematical ability and curiosity, they will find this a rewarding and instructive book to read. The topics discussed are those usual in works on advanced dynamics but the tools are modern—vectors, tensors, matrices and variational principles. Some of the chapter titles are: Variational Principles and Lagrange's Equations, Kinematics of Rigid Body Motion, The Rigid Body Equations of Motion, Special Relativity in Classical Mechanics, The Hamiltonian Equations of Motion, Small Oscillations.

Current references are not given in footnotes, but at the ends of the chapters there are lists of " Suggested References "; these are usually standard text books. The author must be highly commended for adding a few critical comments alongside each reference, for the guidance of the reader, and this practice might well be adopted by others. The comments are extremely revealing as regards the author's outlook and knowledge and it must be said that they show him not to be well acquainted with the application to technical problems of the techniques which he himself expounds. In speaking of Rayleigh's " Theory of Sound," he says: " His (Rayleigh's) treatment is smooth-flowing and clear, and contains rarely discussed topics, as on the effects of constraints and the stationary properties of eigenfrequencies." Well, it may be true that these topics are rarely discussed in the United States of America (although the reviewer doubts this), but certainly this is not true of the United Kingdom. Again, in commenting on Timoshenko and Young's " Advanced Dynamics," he remarks: " A number of unusual topics are also treated, such as methods for the approximate solution of the secular equation, and small vibrations about steady motion." These last comments strongly suggest that the author is out of touch with technical dynamics.

We may sum up by saying that this is an interesting book, but certainly not the average aeronautical engineer's cup of tea.

MARSHAL WITHOUT GLORY. Ewan Butler and Gordon Young. Hodder & Stoughton. London 1951. 287 pages. 17 illustrations. 15s. net.

Though nearly seven years have passed since the Armistice with Germany, recollection of the sordid history of the Nazi leaders still remains distasteful—yet, of them, Hermann Goering, Marshal of the Reich, was no ordinary felon. At Nuremberg his guilt was solemnly adjudged " unique in its enormity," but his biographers neither condone nor condemn, leaving the reader to draw his own conclusions from the impartial evidence they present of the factors which made Goering's life story.

It is a history of pathological degeneration, told with a vivid, simple lucidity which is entirely convincing. Even the youthful Goering was more than average life-size. As successor to the legendary Richthofen in the most famous of all German fighter squadrons in the First World War, his air victories gave him the adulation and prestige of a national hero, everywhere acclaimed by his compatriots. Despite unquestionable bravery it might well have been then that there was sown the psychological seed of the overwhelming conceit which bolstered the Reichsmarschall of later years. As a patriot, outraged by defeat and disillusioned by the Treaty of Versailles, it was almost inevitable that he should turn to Nazism. He met Hitler in 1922, thus early had the movement started, and immediately was so powerfully attracted that the leader's word became his law for ever after. Indeed, although at the end of his career, Goering—like his enemy Ribbentrop, or the Jew-baiting Streicher, mad Hess and the remainder of the Nazi perverts—excused his responsibility for war crimes by saying that he acted under Hitler's orders, unlike the others he defied his judges by insisting that Hitler was right.

Undoubtedly Goering at his trial accepted guilt as accessory to many crimes of which he had not approved, or which were wholly inconsistent with his character, like the Stalag-Luft

III murder of fifty R.A.F. officers. Had he not in 1944 protested to Hitler himself at the lynching of R.A.F. pilots, receiving the furious retort: "I know perfectly well that both Air Forces have come to a mutual agreement of cowardice?" It was significant that Goering dare further dispute the matter by insisting: "We have not come to an agreement of cowardice, but somehow we fliers have always remained comrades no matter how much we fight each other." Yet two years later under cross-examination he could affirm with equal pungency his loyalty to his late leader: "I am not here to justify the Fuhrer nor to glorify him, I am here only to emphasise that I remained faithful to him, for I believe in keeping one's faith not in good times only but in bad times when it is much more difficult."

As the most eminent survivor of the hierarchy, Goering was determined to use the Nuremberg Trial for a last defence of National Socialism, by which not only his own people would evermore remember him, but the entire listening world. To his counsel he could joke, even though fatalistically and unshakeably convinced, from the first day of imprisonment, of his eventual sentence of execution: "Ten years hence, you know, there'll be a statue to me in most German houses. A very small statue, I dare say, but it will be there!" It may be when that time comes other people will also remember that though Germany perpetrated great crimes against mankind it was not Britain, nor even the U.S.A., of which Germany was afraid—but Russia and Communism.

Goering the bombastic, the corrupted—the man who had been a hero, who had shown great ability and risen to vast power and wealth, who had held the affection of his intimates, who had incurred jealousy and hatred, who had known sorrow, poverty, terrible pain and madness—impressed by his intelligence, power of memory, and courage even his British and American jailers. It is not hinted in this biography that his escape from the gallows by swallowing poison under impossible circumstances may even have been by connivance.

HANDBOOK OF AGRICULTURAL PEST CONTROL. S. F. Bailey and L. M. Smith. Industry Publications Inc., New York 1951. 180 pp. Index. Tables. $3.25.

It was with pleasure that the reviewer, who is actively engaged in agricultural pest control, received this book. Here, in convenient size, well printed and laid out, was perhaps the book to be carried during his working hours; a handbook containing all the answers to the questions and problems put to him by anxious farmers.

A first glance through the book reveals its 180 pages divided into three sections and the index of chapter headings includes all aspects of pest control with the exception of entomology. The book is written by two Professors of Entomology of the University of California, and it seems a pity that a chapter on this most important subject was omitted.

Section I deals with "Chemicals" and Chapter 1 gives an impressive list of fungicides, insecticides, herbicides and plant hormones. The following chapters deal with the physical and chemical properties of agricultural chemicals, their compatability and the containers in which they may be obtained (in the U.S.A.), toxicology and spray oil specifications.

Section II on "Machines" describes in five chapters rates of application for sprays and dusts, dusting methods and finally aircraft spraying. This subject, of interest both to aircraft constructor and pest controller unfortunately falls far short of what is desired. Assuming that the authors had investigated pest control by helicopter and fixed-wing aircraft in the United States, the information divulged is poor. At present over two thousand planes are engaged anually in this occupation in the U.S. and more information of how operations are carried out, or the types of pumps and nozzles used, would have been more useful. On page 117 a method of estimating acreage output per hour is given and an example for a light aircraft gives an answer of 436 acres per hour. Yet two pages earlier a table quotes the actual average output for light aircraft as 60 acres per hour—certainly nearer the truth.

Section III deals with a number of subjects—mosquito control, hazards of the pest control occupation and finally a number of tables and formulae.

Perhaps the most useful part of the book lies in some of the tables of which there are 101. But here again, it seems unnecessary to include a table which gives, in one column the total delivery from nozzles in gallons per minute and in the other columns the times to empty tanks of various capacities, *e.g.* at a total nozzle delivery of 10 gallons per minute a 300 gallon tank will be emptied in 30 minutes!

It is difficult to decide for whom this book has been written. Was it for the American farmer or fruit grower who sprays his own crops, or for the contractor who will do the work for him? No! The information is insufficient and in parts irrelevant. Perhaps then the Student will find it of some use, the information therein supplemented by other text books on the subject.

FLIGHT WITHOUT FORMULAE. A. C. Kermode. Sir Isaac Pitman & Sons Ltd., London 1951. 254 pp. 115 figures, 49 photographs. 18s. net. *Second Edition.*

This is the second edition of a book first published in 1940, explaining in simple language, and without mathematics, how and why an aeroplane flies.

New sections have been added—on high speed flight, compressibility effects and jet propulsion—but this is by no means the only difference. The book has been revised throughout, by additions covering modern developments and by alterations in sequence and in emphasis. There are now more figures and twice as many photographs, including the Brabazon, Comet, D.H.108 and other up-to-date examples. Two minor criticisms of detail may be made, the very low rate of climb of the example in Fig. 96 and the old-fashioned appearance of the aeroplane illustrating side-slip on Fig. 103, but these are the only places where the book appears dated. In general, a first class job has been made of the revision.

The first edition was a deliberate attempt to depart from the text book atmosphere. It was written in an orthodox and refreshing style and contained 100 short sections explaining, in a simple and readable way, all aspects of flight. The style has been maintained in the new edition, and there are still 100 short sections. The first edition was a really good introductory book, and its successor is to be recommended quite as warmly.

CORAL CIRCUS. John Joly. Cassell & Co. Ltd. London 1952. 206 pp. 10s. 6d. net. *Fiction.*

A first novel by an author who served in the Fleet Air Arm, this is the story of four Fleet Air Arm pilots. Unable to land on their carrier they put down on an uncharted island in the Pacific which, at one time abandoned by American forces, provides shelter, food of a kind, petrol and a sinister atmosphere. Apart from some licence with improbable ferrying incidents to provide a feminine interest, the flying has the authentic touch and altogether it is quite a good yarn.

CORRESPONDENCE

DESIGN FOR MAINTENANCE

Some excellent material has appeared over the past eighteen months having either direct, or indirect, reference to the Servicing and Maintenance of aircraft and the design considerations given to achieve the ideal.

This has been matter of fact and has dealt with the subject—or at least so it appeared—on particular aircraft after the aircraft as a whole has been projected.

The lessons learned on the latest prototype are rarely given consideration on the type immediately following, due no doubt to the time factor. At the risk of contradiction I would state that present-day large aircraft consume three times the design man-hours that a similar type would have required in 1939. This may be due partly to more stringent specifications. The old adage of " add simplicity and more lightness " is fast being forgotten, while the younger generation of draughtsmen do not possess the flair for rapid and accurate work, they produce either one or the other.

Troubles on previous types are either " modded out " or passed to the operator, who by now has realised it is no use grumbling at the design, so he plans accordingly and incorporates his own mods. Here again Drawing Office labour is at a disadvantage. How many draughtsmen—junior and many senior (but not the very senior)—have field experience? Every opportunity should be given to those who can be relied upon to work with the operator and study his genuine criticisms.

A large percentage of draughtsmen engaged on the last previous type may not be available for the succeeding prototype due to the usual changing population of drawing offices, or their retention on earlier types, without any means of passing on the knowledge gained in modification procedure. This may be due to the system, but is sometimes due to lack of appreciation as to why a certain modification was requested by either Flight Test or the operator.

Such ignorance may persist for years and, if so, it must be the system which needs reviewing. The Chief Designer and his few higher subordinates cannot control the possible repetition of minor atrocities, even though they knew of their past history; they are far too busily engaged on major aerodynamical, weight, and performance problems. I had hoped to see some idealistic proposals after the lectures given by Mr. Bishop, Messrs. Woodall and Higgs, followed by Messrs. Conway and Bound. I would propound a few questions—with my own

comments—to see if anyone is interested in designing with a view to really easy maintenance and cheap servicing. I would refer mainly to aircraft of 100,000 lb. all-up weight and over —the larger they are the more my comments should apply in general, while they are not entirely irrelevant to aircraft of only 50,000 lb. all-up weight—civil or military. Fighters are not included because, due to stringent and ever-changing specifications, they require more independent treatment.

Questions and Comments

(*1*) When projecting a new design, frontal area is one of the important studies. Having arrived at the optimum which means the minimum, it is suggested that it be increased by at least 5 per cent. and if new and untried engines are to be installed, 10 per cent. may not be excessive. The full percentage of increase may not materialise and just whereabouts on the aircraft it will happen will manifest itself as the design proceeds. One thing is certain, it will have no effect on the tare weight which will be absorbed in improvising, if sufficient volume is not available at the outset for easy access. There will also be a distinct saving in design time—when items can be installed in a reasonably straightforward manner, snags and miscalculations disappear—with a consequent improvement in date of first flight!

(*2*) Group the systems wherever possible; it is not always possible and when it is, does not provide every answer, but it should be possible to group all items of any service that require daily or short period servicing.

(*3*) The use of stressed skin wings is now universal and there is no real alternative, but they do restrict the use of the wing as a home for the plumbing, and so on. No hand hole is large enough, and access panels require a multiplicity of screws. There is an opportunity here for some clever work if accessibility to vital items is to be 100 per cent. effective. Similar remarks apply to portions of the fuselage, particularly at the two ends.

(*4*) A more careful selection of materials, particularly on Marine Aircraft, or those likely to operate from seaside aerodromes will pay handsome dividends so far as the operator is concerned, and complete sealing of vulnerable overlaps and joints is essential.

(*5*) Why must the Flight Engineer be on top of the Pilot? This results in a congested flight deck and long leads of every conceivable system from the front spar to Instrument Panels.

In an aircraft of the size under discussion, the whole of the Flight Engineer's installation could be between the spar frames, giving more room (I hope), and much shorter and direct leads of all that runs to or from this position from wing installations.

In most cases inter-communication by headset is essential, so the added distance between Pilot and Flight Engineer does not introduce any complications. An interesting example of an isolated engineer on a small aircraft is the Catalina, which was (is) one of the easiest to operate, co-operation being excellent. The throttle controls are the only ones which require additional consideration, but even so the inter-connection may be much easier than is possible under present restricted flight deck conditions. Careful forethought would be required in the project stage.

(*6*) Aircraft of this size may, and most probably will, consist of two decks. The underside of the top deck is a useful place on which to hang most fore and aft services, but when being projected, thought should be given to the head room on the lower deck. Whatever is projected stands a fair chance of being reduced, but if allowance is made for a false ceiling, the available space will be blessed by all, without any sacrifice of passenger comfort.

You see now where some of the 5 per cent. increase of frontal area could be used!

(*7*) Pressurisation and air conditioning is now an accepted fact for all large aircraft, and the ducts for both fresh and re-circulated air can be quite sizeable if pressure drops are to be within reasonable limits. They should be sized up in the project stage, as otherwise they increase as the job proceeds and obliterate some well-meant engineering which was ideal for servicing. Furthermore, they reduce volume assumed by Project Office as " Saleable."

(*8*) Electronics are also with us for ever. Up to now, with few exceptions, their valve life is short and unpredictable, while what appear similar units, doing similar work, have entirely different lives allotted by their makers.

Should the long-lived set be installed first, and the installation later copied for the shorter life unit, some difficulty in servicing may well be experienced.

(*9*) Hydraulics are not to be found in abundance on Civil aircraft, and where used, should consist of self-contained units, each entirely independent of the other and capable of being changed in entirety if necessary without disturbing other services.

(*10*) The use of high altitude/low temperature lubricants needs careful appreciation, and the smallest number of lubricants compatible with efficient operation should be aimed at. One type of grease gun nipple only should be fitted and if possible one type of grease made universal.

A system of identification at all lubrication points should be incorporated. This should consist of diagrammatic as well as colour symbols; it assists in speedy work even with a change of servicing personnel.

(*11*) The use of power-driven assembly tools, *e.g.* screwdrivers and so on, puts a responsibility on the Drawing Office to ensure that items tightened or otherwise manipulated by these tools are capable of withstanding the applied torque, which maximum should be clearly indicated on the relevant drawings. The operator will otherwise find that he either cannot remove the item or that deformation has occurred which necessitates a replacement not otherwise anticipated.

(*12*) The use of self-lubricating bushes should be called for only where conditions are favourable. Extremely dry and warm situations are not conducive to long life as the material will tend to dry out and possibly crumble. Alternatively, if exposed to the elements they are suspect of causing the surrounding light alloy to corrode. Used with discretion there are places on aircraft where they can be used, but the writer is not a strong supporter of them, particularly on marine aircraft.

(*13*) Mr. Bishop's drive to eliminate electrical indicators is shared. Unfortunately, there are so many items which require indication, that it is impossible to arrange mechanical indication in every case. It should be possible to arrange mechanical indication to inside the hull/fuselage —thence electrically, on the assumption that any electrical fault could then be traced in flight. I refer to the really important indication—so much of that at present fitted is relatively unimportant.

Such items as well-tried electrical r.p.m. indicators, and so on, are outside my criticism, while fuel contents cannot very well be transmitted by mechanical means.

(*14*) The use of circlips should not be permitted for holding in and registering ball races or other similar jobs where a more positive and engineering method can be used. Those who have had to break down a few mechanical items will no doubt agree that circlips are like eggs, good in parts.

(*15*) Due to considerations of weight saving, the use of really thick and tough, yet resilient rubbing strips on such things as cowling, and so on, is not welcomed, yet how much difficulty could be overcome, and how much time and labour saved if only the designer had not been so keen on saving a few ounces on an engine installation—or similar item.

The use of self-tapping screws for this (and other) type(s) of fixing is not entirely deprecated, but the use of coarse thread screws and a proprietary " flat plate " type of lock nut does enable a quick replacement when necessary. Some later aircraft are showing signs of coming into line with this method.

(*16*) How many aircraft have all the drains in their air lines really accessible?

(*17*) How often are several bolts (and nuts) used when less would suffice if only dowels had been used to help in taking the shear loads?

(*18*) No matter what is neglected in the general run of all things which should be beyond criticism, it is essential that everything connected with the pilot's cockpit check and engine run-up must be so accessible as to be almost self-rectifying when defects occur.

By the time the check is made the aircraft is most probably full of passengers and time of take-off quite near. If anything cracks then, speed is of utmost importance and time spent in design for the easiest of easy servicing of these systems is well repayed.

When the weather is bad the pilot is inclined, and rightly so, to be extra fussy.

(*19*) The flexing of large wings may give troubles not fully appreciated in the design stage and care should be exercised in making allowance for interference caused by deflection. Cables may be compensated, but torque tubes and push rods need allowances, which if not given will be a constant source of maintenance. Electric cables and hydraulic pipes will chafe, but fuel and oil pipes are usually cared for.

(*20*) Hinged instrument panels are almost a standard on all aircraft, but what of pilot's seats (and others), where services under the floor have to be examined by a man in the inverted position?

The fire bottle installation often gets relegated to a secondary position, merely because it is static. If one day the bottles are empty when required for use, someone may improve the facilities for their regular examination.

There are other items and groups which are subject to severe criticism.

L. S. Ash, *Associate Fellow.*

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